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5.—Some Interesting Stomatapoda—mostly from Western Australia

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Twenty-five species of stomatopods are dealt with, stress being laid upon geographical distribution. Additional localities are given for eight species previously known from Western Australia, together with eight new records for Western Australia, one new record for Lord Howe Island, and three for Australia.

Three species are recorded from Christmas Island (Indian Ocean) and one from the Molluccas.

Squilla microphthalma H. Milne Edwards is redescribed and *Lysiosquilla brazieri* Miers resurrected as a subspecies of *L. latifrons* (de Haan).

Introduction

Since the publication of a check list of the Australian stomatopods (Stephenson and McNeill 1955) and a recent short note (Stephenson 1960) additional specimens from five main sources have been examined:—

(a) extensive collections from the Western Australian Museum, Perth;
(b) a few specimens from the Australian Museum, Sydney, sorted from general collections made in North Western Australia;
(c) specimens recently obtained in Eastern and Northern Australia;
(d) a small collection from Christmas Island in the Indian Ocean; and
(e) the small series of stomatopods in the Macleay Museum (University of Sydney).

In reporting upon these, specimens falling within the known limits of distribution have been omitted unless of special interest. The following categories are considered separately below:—

(a) species whose known distribution has been extended;
(b) new Australian records; and
(c) redescribed species.

In this paper, lengths are measured in a mid-dorsal line from the posterior end of the telson (as near practicable, excluding spines) to the anterior edge of the carapace excluding the rostrum.

Extensions to Ranges

In general, only brief literature citations are given, these being adequate for identification. Fuller references and details of the known Australian distributions are given in Stephenson and McNeill (1955).

Squilla fabricii Holthuis, 1941, pp. 249-53, text-fig. 1.

One, Macleay Museum, labelled "Molluccas". The species is known from very few specimens from the erstwhile Dutch East Indies.

Squilla granti Stephenson, 1953, pp. 201-8, Fig. 1A-D, Fig. 2A, B, D, F. G.

Two, Port Walcott, W. Australia, 8 fm, sand with occasional sponges and corals, coll. R. D. Royce ("Davena"), 3/vi/1960, W. Aust. Mus. Reg. No. 20 (b)-61.

Two, 4-5 miles from Urquhart Point, 3-3½ fm, Westminster dredging, Weipa, Emberley River, Gulf of Carpentaria, Queensland, coll. G. Webster, 1/vii/1961, Aust. Mus. Reg. No. P12543.

Previously known only from Queensland. The present specimens differ from the original material (Stephenson 1953) in certain minor respects, e.g., more pigmented. Black pigment lines the gastric grooves of the carapace and is present on the outer uropod. Here diffuse patches occur on the distal portions of the penultimate segments and on the proximal portion of the ultimate segments.

Squilla incrnata Tate. Kemp, 1913, pp. 70-2, Pl. V, Figs. 57-9 (as *S. oratoria* var *perpensa*).

Two, Entrance Point, Broome, W. Australia between tides on rocky reef shore, Aug. 1929, coll. A. A. Livingstone, Aust. Mus. Reg. No. P13545.

New record for Western Australia.

Squilla laevis Hess. Kemp, 1913, pp. 49-50, Pl. III, Figs. 35-7.

The Western Australian Museum collections include:—

One, Exmouth Gulf, W. Australia, trawled, coll. R. McKay, M.V. "Lancelin", Oct. 1958, Reg. No. 8-61.

Two, 40 miles S.W. of Carnarvon, Shark Bay, W. Australia, trawled, coll. via. A. Snell, June, 1960, Reg. No. 42-61.

The Australian Museum collections include:—

One, between Broome and Wallal (Ninety Mile Beach), W. Australia, dredged about 7 fm, coll. R. Bourne, Reg. No. P10016.

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The species is recorded from Queensland, New South Wales, Victoria, South Australia and Western Australia. The present records extend the northern range in Western Australia, just as recent collecting has extended the Queensland range (Stephenson 1960).

Squilla mcneilli Stephenson, 1953, pp. 213-8, Fig. 4A-F.

Dr. A. A. Racek reports (in correspondence):—"This species has been found very commonly between about 60 to 120 fathoms in an area stretching from about due east of Barranjoey Lighthouse (Hawkesbury River) to due east of Stockton, and in fact it has been so common that I did not suspect it being an unusual species at all . . . . . Whatever the optimal depth of this species might be, *S. mcneilli* does not seem to occur at all this side of 100 m or 50 fathoms." Eleven species collected in the above area, 3rd-9th July, 1959, were kindly forwarded by Dr. Racek.

The majority of specimens had raptorial dactyli with six teeth not five as in the type material. Some specimens had six teeth on one claw and five on the other.

The species had been recorded off the New South Wales coast from Newcastle to Green Cape in 25-90 fm.

Squilla miles Hess. Hale, 1924, pp. 492-5, Pl. XXXII, Fig. 1, text-fig. 381a-i.

One, near Albany, Cape Riche, W. Australia, herring net, coll. A. Kalnins, March, 1954, W. Aust. Mus. Reg. No. 38-61.

Juvenile (30mm), Shark Bay, W. Australia, night drift, M.V. "Lancelin", 31/iii/1957, W. Aust. Mus. Reg. No. 9-61.

Two, 4 Mile Reef off Busselton, 60 ft, stomach of fiddle-ray, coll. B. Wilson, 28/xii/1958, W. Aust. Mus. Reg. No. 46-61.

Common on the southern shores of Australia. Previously recorded from Western Australia (but from an unknown locality) by Alexander (1916*a*), from Cottesloe by Hale (1929*b*) and from Albany by Stephenson and McNeill (1955). The present records extend the northern range of the species, particularly since Hess' (1865) locality of "Sydney" is suspect (see Stephenson and McNeill 1955).

Squilla raphidea Fabricius. Kemp, 1913, pp. 88-92, Pl. VII, Fig. 77.

One, Wyndham, W. Australia, coll. R. G. Patterson, 1956, W. Aust. Mus. Reg. No. 170-56.

New record for Western Australia, previously known from the Northern Territory, New South Wales and Queensland.

Squilla terrareginensis Stephenson, 1953, pp. 208-13, Fig. 3A, B.

Male, Carnarvon, W. Australia, off reef, N. Paul via P. Crackel, Feb. 1962, W. Aust. Mus. Reg. No. 148-62.

Known previously only from the type material from N. Queensland.

Lysiosquilla multifasciata Wood-Mason. Chopra, 1939, pp. 162-5, Figs. 8, 9.

Two, Barred Creek, 40 miles N. of Broome, W. Australia, mangrove flats, low tide, coll. A. Kalnins, 5-10/i/1960, W. Aust. Mus. Reg. No. 35-61.

One, Port Walcott, W. Australia, 8 fm sand with occasional sponge and corals, coll. R. D. Royce ("Davena"), 3/vi/1960, W. Aust. Mus. Reg. No. 20 (d)-61.

New records for Western Australia. Only one specimen was previously known from Australia, from Dunk I., Family Group, Queensland.

Lysiosquilla osculans Hale, 1924, pp. 501-2, Pl. XXXIII, Fig. 3, text-fig. 384 (as *Lysiosquilla vercoi* var *osculans*).

Two, Cottesloe, W. Australia, from gullet of flounder, coll. D. Diamond, 1940, W. Aust. Mus. Reg. No. 14/15-40.

New record for Western Australia, previously known only from Victoria and South Australia.

Pseudosquilla ciliata (Fabricius). Kemp, 1913, pp. 96-100. Bigelow, 1931, pp. 152-6, text-figs. 3-6. Dollfus, 1938, pp. 198-200, Fig. 8 (with synonymy).

A single specimen is present in the Macleay Museum labelled "Lord Howe Island."

Within Australia previously recorded only from Queensland.

Pseudosquilla ornata Miers. Kemp, 1913, pp. 100-1. Komai, 1927, pp. 324-5, Pl. XIV, Figs. 2-2b.

One, Christmas I., coll. E. Carr, July, 1961, W. Aust. Mus. Reg. No. 110-61.

A widespread Indo-West Pacific species, apparently never common, and not so far recorded from Australia.

Gonodactylus chiragra (Fabricius). Kemp, 1913, pp. 155-62, Pl. IX, Fig. 107, Fig. 2 on p. 161. Dollfus, 1938, pp. 205-13, text-figs. 14, 15 (with synonymy).

This widely distributed species is represented in the Western Australian Museum by collections from:—

Yampi Sound; Point Ganthcaume; Broome; Port Hedland; Delambre I., Enderby I. (Dampier Archipelago); Point Cloates; Maud Landing; Carnarvon; Cape St. Cricq; Cape Inscription; North I., Rat I. and Gun I. (Abrolhos Group); Quobba; Dixon I., Nichol Bay; and also from Christmas I.

Previously recorded in Western Australia by Miers (1880*b*) from Swan River and the Abrolhos, by Pocock (1893) from Baudin I., Troughton I., Damma I., and Baleine Bank, by Alexander (1916*a*, *b*) from Port Hedland, and by Balss (1921) from the Cape Jaubert vicinity.

Gonodactylus falcatus (Forskål). Kemp, 1913, pp. 167-9, Pl. IX, Fig. 113, text-fig. 2 (as *G. glabrous* Brooks). Dollfus, 1938, pp. 217-222, figs. 18-20 (as *G. glaber* Brooks, with synonymy).

This widely distributed species is represented in the Western Australian Museum collections by specimens from:—

Yampi Sound; Thevenard I.; Shark Bay; and Cockburn Sound. It has been recorded from Shark Bay by Alexander (1916*a*) and Dirk Hartog I. by Hale (1929*b*).

Gonodactylus graphurus Miers. Kemp, 1913, pp. 169-71, text-fig. 1 on p. 170.

This widely distributed species is represented in the Western Australian Museum collections by specimens from:—

Broome; Port Hedland; Malus I., Gidley I., and Mermaid Straits (Dampier Archipelago); Wreck Point, Abrolhos Is.; and Port Walcott. Previously recorded in Western Australia from Nichol Bay by Miers (1880*b*), from N.W. Australia, Baudin I., and Baleine Bank by Pocock (1893) and from the Cape Jaubert vicinity by Balss (1921).

Gonodactylus pulchellus Miers. Kemp, 1913, pp. 177-9, Pl. X, Figs. 117-8. Dollfus, 1938, pp. 224-6, Fig. 22 (with synonymy).

Two off Ganthcame Point, Broome, W. Australia, dredged 4 fm. Aug. 1929, coll. A. A. Livingstone, Aust. Mus. Reg. No. 13544.

One, 25 miles N.W. of Angel I., Dampier Archipelago, W. Australia, "Honolulu" dredge, 37 fm, sand, coll. R. D. Royce ("Davena"), 2/vi/1960, W. Aust. Mus. Reg. No. 18-61.

New record for Western Australia, with only two previous Australian records, from Princess Charlotte Bay and Hayman Island, both in Queensland.

Gonodactylus stoliurus (Müller). Kemp, 1913, pp. 184-5.

One, Maud Landing, N.W. Australia, 10 fm. weed and sand on rock, "Honolulu" dredge, coll. R. D. Royce ("Davena") 20/v/1960, W. Aust. Mus. Reg. No. 10-61.

One, 5 Mile Fence, S. of N.W. Cape, W. Australia, reef at low tide, coll. R. George and P. Cawthorn, 3/iv/1961, W. Aust. Mus. Reg. No. 52-61.

According to Pocock (1893), Hansen considered that Miers' (1880*b*, c) record of *G. trispinosus* from Shark Bay refers to the present species. *G. stoliurus* has been recorded from Lancelin Is., Western Australia (Stephenson and McNeill 1955).

Gonodactylus trispinosus Dana. Borradaile, 1898, p. 33, Pl. V, Figs. 1, 1a (as *Protosquilla trispinosa*). Kemp, 1913, pp. 180-1.

One, with malformed telson, N.E. of Malus I., Dampier Archipelago, W. Australia, 10 fm, "Honolulu" dredge, coll. R. D. Royce ("Davena"), 31/v/1960, W. Aust. Mus. Reg. No. 13 (b)-60.

The left half of the central portion of the telson is deformed and bent ventrally, giving a wider than normal separation between right and left halves, with resultant difficulty in keying the specimen.

Recorded previously from W. Australia as follows:—

Swan River (Miers 1880*b*), Baleine Bank (Pocock 1893) and Cape Jaubert vicinity (Balss 1921): also from Queensland (Hale 1929*a*, Stephenson and McNeill 1955). Nevertheless sufficiently uncommon to be worthy of mention.

The specimen from Swan River mentioned by Miers (1880*b*, c) was evidently White's (1847) type. Although *G. trispinosus* White 1847 is a *nomen nudum* (see Kemp 1913, p. 180), the name *G. trispinosus* was evidently first applied to this Western Australian specimen (see Miers 1880*b*, *c*). Two further Western Australian specimens referred by Miers (1880*b*, *c*) to the present species are now regarded as *G. stoliurus*.

Odontodactylus cultrifer (White). Kemp, 1913, pp. 137-8, pp. 138-9 (as *O. carnifer* (Pocock)).

Two, W. side, Exmouth Gulf, W. Australia, in trawl, coll. K. Godfrey, M.V. "Lancelin", 26/ii/1956, W. Aust. Mus. Reg. No. 41-61.

New record for Western Australia, previously recorded from Queensland.

Odontodactylus japonicus (de Haan). Komai, 1927, pp. 335-6, Pl. XIII, Fig. 2.

One, Shark Bay *or* Exmouth Gulf, W. Australia, trawled, coll. R. McKay, M.V. "Lancelin", June-Oct. 1958, W. Aust. Mus. Reg. No. 14-61.

Alexander's (1916*b*) record from Broome, Western Australia was queried by Stephenson and McNeill (1955), but since the species is now known from Western Australia and from the Capricorn Group, Queensland (Stephenson 1960), this querying appears unjustified.

Odontodactylus scyllarus (L.) Kemp, 1913, pp. 135-7. Komai, 1927, pp. 335-6, Pl. XIII, Fig. 2.

One, Christmas I., coll. E. Carr, July, 1961, W. Aust. Mus. Reg. No. 111-61.

While widespread throughout the Indo-West Pacific area, this species nowhere appears common. A specimen from Wewak, New Guinea, was recently received at the University of Queensland.

New Australian Records

Squilla gonypetes Kemp 1911

Squilla affinis Pocock, 1893, p. 474 (*partim* fide Kemp, 1913).
Squilla gorypetes Lloyd, 1908, p. 33 (*sine desc.*).
Squilla gonypetes Kemp, 1911, pp. 96-7; 1913, pp. 54-5, Pl. IV, Figs. 42-44. Sunier, 1918, pp. 66-7. Kemp and Chopra, 1921, pp. 300-1. Hansen, 1926, p. 10. Gravier, 1938, pp. 166-8, Fig. 1. Stephenson and McNeill, 1955, p. 256 (in key).

♀ (34 mm) approx. 10 miles N. of Long I., off Onslow, W. Australia, coll. B. R. Wilson ("Davena"), 17/vi/1960, W. Aust. Mus. Reg. No. 29-61.

The pigmentation of the present specimen follows exactly that mentioned by Pocock (1893) and described by Kemp (1913). Previously the species had been recorded from Burma, the Andaman Is., Arakan Coast, Persian Gulf, Holothuria Bank (China Sea), Mergui Archipelago, the Java Seas and the Gulf of Suez, but not from Australia.

Squilla multicarinata White 1848

Squilla multicarinata White 1848, p. 144, Annulosa Pl. VI, Fig. 1, 1a; 1849, pp. 381-2. Miers 1880*a*, p. 20. Bigelow, 1895, p. 511 (in key). Nobili, 1903, p. 38. Kemp, 1913, pp. 86-8, p. 196, Pl. VI, Figs. 73-6. Sunier, 1918, p. 70. Kemp and Chopra, 1921, p. 307. Parisi, 1922, pp. 102-3. Komai, 1927, p. 322. Gravier, 1938, pp. 174-7, Fig. 4.

Damaged ♀ (estimated length *c.* 39 mm), 5 or 6 miles off Bezout I., Dampier Archipelago, W. Australia, coll. B. R. Wilson ("Davena"), 5/vi/1960, W. Aust. Mus. Reg. No. 27-61.

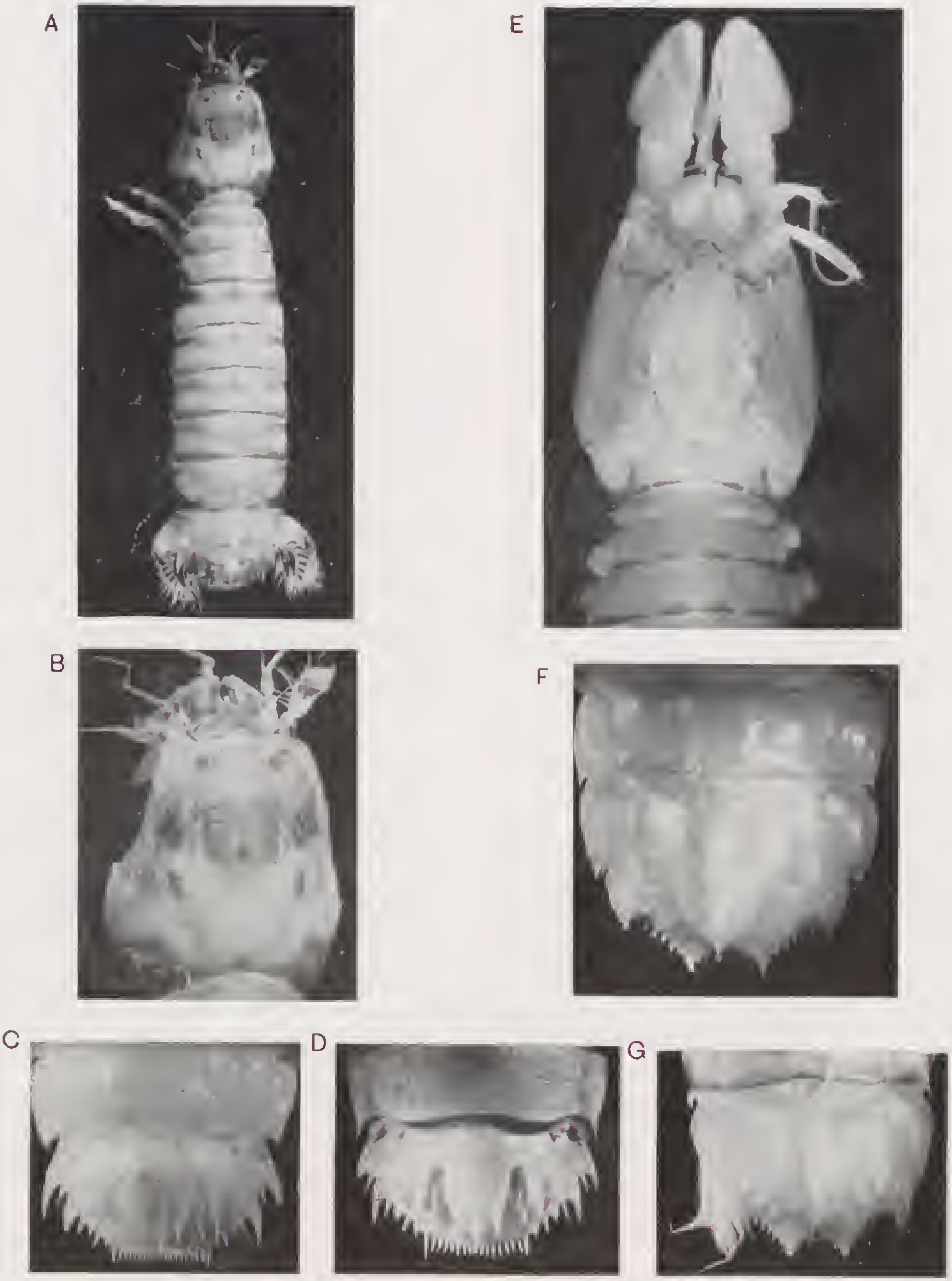

PLATE I

Figs. A, B, C, D—*Lysiosquilla latifrons brazieri.*
Fig. A.—55mm specimen (whole); Fig. B.—55 mm specimen (carapace); Fig. C.—80 mm specimen (telson); Fig. D.—75 mm specimen (telson). Figs. E, F, G—*Squilla microphthalma;* Fig. E.—32 mm specimen (carapace, etc.); Fig. F.—39 mm specimen (telson); Fig. G.—28 mm specimen (telson).

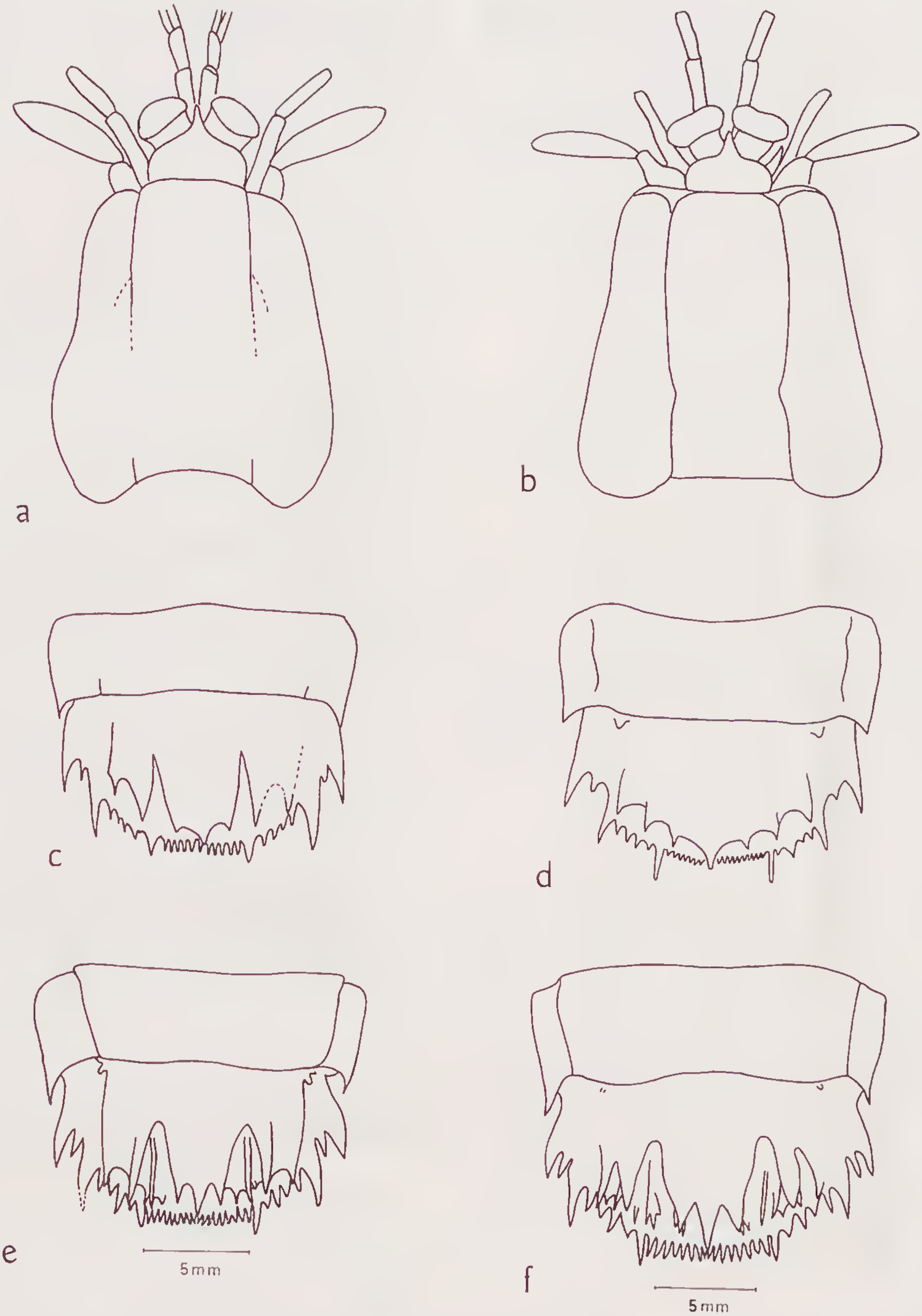

Fig. 1.—*Lysiosquilla latifrons brazieri*—a.—Carapace, etc. of *L. latifrons* after de Haan (1844); b.—Carapace, etc. of *L. latifrons* after Komai (1927); c.—Telson of *L. latifrons* after de Haan (1844); d.—Telson of *L. latifrons* after Komai (1927); e.—Telson of 80 mm specimen; f.—Telson of 75 mm specimen.

Previously known from Japan, the Philippines. Singapore, Hongkong, Christmas I., South India (Kemp 1913), Java Seas (Sunier 1918), Singapore (Kemp and Chopra 1921), and Gulf of Suez (Gravier 1938), but not from Australia.

In the key of Stephenson and McNeill (1955), the species comes out by the following route:—1, 2, 4, 23 (first alternative). With *S. lirata* Kemp and Chopra (1921) it is distinguished by the possession of a bilobed lateral process on the sixth thoracic somite, and by the entire surface of carapace and abdomen being multicarinate. It is separated from *S. lirata* by the possession of a mandibular palp, by having five teeth on the raptorial dactylus, and by other features (see Kemp and Chopra 1921).

Redescribed Species

Lysiosquilla latifrons brazieri Miers 1880*a*

(Figs. 1e, 1f; Plate 1, Figs. A, B, C, D)

Lysiosquilla brazieri Miers, 1880*a*, p. 11, Pl. I, Figs. 3-6; 1880*b*, p. 125. Haswell, 1882, p. 206. Bigelow, 1893, p. 503 (in key). Chilton, 1911, p. 139.

Lysiosquilla latifrons (de Haan). Kemp, 1913, pp. 128-9 *(partim)*. Stephenson and McNeill, 1955, p. 248.

non *Squilla latifrons* de Haan, 1844, Pl. LI, Fig. 3; 1849, p. 222.

non *Lysiosquilla (Coronis) latifrons* (de Haan). Miers 1880*a*, pp. 10-11.

non *Lysiosquilla latifrons* (de Haan). Rathbun, 1902, p. 54. Komai, 1927, pp. 333-5, Pl. XIV, Figs. 3, 3a, 3b.

Discussion of Synonymy

Miers' original description, based upon a female specimen from New South Wales, distinguished *L. brazieri* from *L. latifrons* as follows:—(a) having six teeth on each raptorial dactylus instead of seven, (b) having a telson armed with more numerous spinules (*c.* 14), (c) not possessing a median sinus on the telson, and (d) in having the short appendages of the last pair of thoracic limbs almost linear.

These distinctions have been shown to have no taxonomic value.

(a) Rathbun (1902) noted that de Haan's original description of *S. latifrons* from Japan did not conform with his figure, where six teeth are shown on the right raptorial dactylus. Also her own Japanese specimen possessed six teeth on each dactylus. The same applies to the Japanese specimen described by Komai (1927).

(b) Rathbun (1902) noted in her Japanese specimen that the telson bore 12 small spines on one side and 11 on the other, and later Chilton (1911) noted upon New Zealand specimens of *L. brazieri* that there were only 10 spinules upon each side of the telson.

(c) The absence of a median sinus is of little value, because Chilton's material had "a slight indication of a sinus on the posterior margin of the terminal segment".

(d) Kemp (1913) inferred that a linear short appendage on the last pair of thoracic limbs was present in de Haan's species, and this is confirmed by Komai's (1927) description.

The described distinctions between Miers' and de Haan's species are invalid and all recent workers have relegated Miers' name to the synonymy (Chilton 1911, Kemp 1913, Komai 1927, and Stephenson and McNeill 1955).

However, certain other characteristics are of possible taxonomic value. These are colour, and ornamentation of the telson.

Colour.—Two freshly collected specimens from the New South Wales/Queensland border waters showed constant colour differences as compared with the Japanese specimen described by Komai. Certain of these differences were visible even in an old dried specimen from Port Jackson in the Australian Museum.

Ornamentation of the telson.—There are constant differences between the Australian material and the Japanese.

To date only three Japanese specimens have been reported in the literature (de Haan's, Rathbun's, and Komai's), plus two from New Zealand (Chilton's—omitting the numerous washed up specimens which were not retained), and two from Australia (Miers', and that of Stephenson and McNeill which is relisted below). Attempts have been made to obtain material from New Zealand (particularly Chilton's specimens) but these have failed. Until more material has been examined it must remain uncertain whether there are intergrades in colouration and telson ornamentation between the Northern and Southern Hemisphere forms. On the present inadequate data the two forms appear to be separate both geographically and morphologically, although the structural differences are much less than usually found between stomatopod species. For these reasons Miers' species is revived and given subspecific status.

Material Examined

♀ (75 mm), Port Jackson, N.S. Wales, coll. Mr. Tiley, dredge "Samson", Aust. Mus. Reg. No. P5487. (Note: the abdominal segments are telescoped in this dried specimen, which is considerably the largest of the three examined.)

♀ (80 mm), of Tweed Heads, Queensland/N.S. Wales border, prawn trawled on clean sand in 20 fm, 11/iii/1961, coll. W.S. (*Squilla laevis* was the dominant stomatopod in the collection). (Note: left raptorial claw missing; specimen to be deposited in the Australian Museum.)

♀ (55 mm), off Kingscliff, Northern N.S. Wales, in prawn trawl at 31 fm, June, 1961, coll. L. Wale. (Note: both raptorial claws missing; specimen to be deposited in the Queensland Museum.)

Material Illustrated

Whole specimen and carapace—55 mm specimen. Telson—80 mm specimen (Fig. 1e; Pl. 1, Fig. C); 75 mm specimen (Fig. 1f; Pl. 1, Fig. D).

Description

The present material agrees with Komai's (1927) description in all respects excepting the following:—

Colour.—In *L. latifrons* Komai describes the carapace as "marked with three dark bands rather obviously defined". In the present specimens the posterolateral areas of the carapace are conspicuously sooty black while the anterior halves are diffusely mottled and spotted with black to a definite pattern (see Pl. I, Figs. A, B). The central of Komai's three dark bands

is represented only by two dark spots. Additional darker pigmented areas on the Australian specimens comprise—the anterolateral portions of the first abdominal somite and the endopodite of the uropod. The latter carries a central paler line.

Telson.—Komai describes this as "nearly as long as broad" but in his figure, and also in de Haan's, and in the present specimens it is about half as long as broad.

Komai described the ornamentation of the dorsal surface of the telson as follows:—"...... set with a row of seven acute spines situated at equal intervals near the posterior margin; of these spines the median somewhat surpasses the rest in thickness; the other three pairs are gradually longer outwards; the submedian and intermediate spines as well as the latter and the lateral spine, are interposed each with a shallow longitudinal furrow, while such a furrow does not exist between the submedian spines and the median spine, so that the median three spines make one group, and the lateral four are separated from the other." Komai's description agrees closely with de Haan's original figure of the telson (see Figs. 1c, 1d).

In the present material Komai's seven acute spines are present, with a similar central grouping of three, and with four more lateral spines. However, the intermediate spines are separated from the submedians by a broad and fairly deep excavation typically bearing additional spines. The laterals are separated from the intermediates by an almost equally broad, but typically shallow excavation. These features are clearly shown in Miers' figure on *L. brazieri* (Miers 1880*a*, Pl. I, Fig. 3). On a lower level than the above large spines, and slightly posterior to them (but still well forward of the terminal spinulation) further spinules or spines are present, either as rows or reduced to isolated spines (see Figs. 1e, 1f; Pl. I, Figs. C, D).

The following variations in spinulation of the dorsal surface of the telson occur in the present material:—

75 mm specimen.—Left space between submedian and intermediate dorsal spines with one spine and a spinule, right space with a tubercle and an elongated spine. Two confusedly arranged lower rows of spines are present, comprising 11 spines.

80 mm specimen.—Spaces between submedian and intermediate dorsal spines each with a long spine. On the left there are two smaller spines, and on the right a single smaller spine, these corresponding to the lower rows of the above specimen.

55 mm specimen.—As 80 mm specimen except single lower spine or spinule on each side.

The numbers of smaller spines on the posterior margin of the telson between the mobile submedians are as follows:—75 mm specimen—8 spines and one minute spinule on either side of the mid line; 80 mm specimen—9 spines on each side with a minute spinule just left of centre; 55 mm specimen—9 spines on each side. Miers' figure of *L. brazieri* (1880*a*, Pl. I, Fig. 3) shows about 7 spines on either side (total c. 14) not 14 on either side as Chilton inferred. Chilton's own material had 10 spines on either side. These numbers overlap with those of *L. latifrons* from Japan, which are evidently at least equally variable.

In dorsal view the lateral margins of the carapace in *L. latifrons* have been figured as rounded by de Haan (see Fig. 1a), and relatively straight by Komai (see Fig. 1b). In the present specimens they are rounded (see Pl. I, Figs. A, B).

Squilla microphthalma H. Milne-Edwards, 1837
(Figs. 2a, 2d; Plate I, Figs. E, F, G)

Squilla microphthalma, H. Milne-Edwards, 1837, p. 523. de Haan, 1849, p. 221. Bigelow, 1895, p. 509. Jurich, 1904, pp. 368-9, Pl. XXVI, Fig. 1. Kemp, 1913, pp. 31-3, Pl. I, Figs. 17-20. Kemp and Chopra, 1921, pp. 299-300. Serène, 1952, pp. 5-11, text-figs. 10, 11, 16, 17, 20; Pl. I, Figs. 2, 5; Pl. II, Figs. 2, 5 (under *S. depressa*).

Chlorida microphthalma (H. Milne Edwards), Eydoux and Souleyet, 1841, pp. 264, 266 (fide Kemp 1913—not seen).

Chloridella microphthalma (H. Milne-Edwards), Wood-Mason, 1895, p. 8, Pl. IV, Figs. 1-5. de Man, 1898, pp. 691-3, Pl. 38, Figs. 76, 76a.

non *Chloridella microphthalma (depressa)* Miers 1880*a*, p. 14, Pl. II, Figs. 1-4 (= *S. depressa* Miers)).

non *Chloridella microphthalma* Haswell, 1882, p. 207 (= *S. depressa* (Miers)).

Discussion of Synonymy

Serène (1952) has shown that previous records of *S. microphthalma* from Australia refer to *S. depressa* Miers. In comparing these two species he redescribed *S. microphthalma* on the basis of two specimens from Indo China, and illustrated the species extensively. The present material differs from Serène's redescription of *S. microphthalma* in several particulars, including:—

(a) carapace shape, with a broader front and less inclined margins (compare Fig. 2a and c);

(b) shape of rostrum, shorter (compare Fig. 2a and c);

(c) number of denticles between submedian marginal teeth of telson, with 3-4 pairs (typically 4) as against 2 pairs; and

(d) shape of bifurcate process of the uropods.
In the present specimens the process is relatively stouter, and with a more clearly sinuous curve in front of the external lobe of the longer spine (compare Fig. 2d. and f).

Serène's figured specimens closely resemble Jurich's from Zanzibar, while the present specimens closely resemble Kemp's from Karachi and Madras and de Man's from Indonesia.

The differences between these two groups of specimens lie within the range to be expected within a stomatopod species, particularly since Serène and Jurich had relatively large specimens (lengths 85 mm and 67 mm respectively). This conclusion has been reinforced by examination of a specimen from Zanzibar kindly forwarded by Dr. A. J. Bruce. The specimen (♂, 4.2 mm) bears the following habitat data—"outflow of mangrove swamp, thick black mud, trawled 5 fms, Mto Zingwe Zingwe, Zanzibar

Island, 4/vii/1961." This specimen is intermediate between Serène's and the Australian material as follows:—(a) resembles Serène's in having a long rostrum and having only two pairs of denticles between the submedian teeth of the telson and (b) resembles the Australian material in the relatively broad and slightly inclined margins of the carapace, and in the shape of the bifurcate process of the uropods (although the external lobe is less strongly developed).

Material Examined

♂ (20mm) Roebuck Bay, W. Australia, between tides on flats, 8/viii/1929, coll. A. A. Livingstone, Aust. Mus. Reg. No. P13540.

♂ (32 mm), ♀ (39 mm) Roebuck Bay, W. Australia, between tides sand flat, 8/viii/1929, coll. A. A. Livingstone, Aust. Mus. Reg. No. P13541.

♂ (28 mm) W. side Fort Hill, Port Darwin, N. Territory, between tides, coll. A. A. Livingstone, Aust. Mus. Reg. No. P13542.

Material Illustrated

Carapace etc.—32 mm specimen. Telson—39 mm specimen (Pl. I, Fig. F) and 28 mm specimen (Pl. I, Fig. G). Front end of carapace and rostrum—39 mm specimen (Fig. 2a). Bifurcate process of uropod—32 mm specimen (Fig. 2d).

Description

Eyes.—Eyestalks short and broad, length approximately three-quarters that of the basal segment of the antennular peduncle, maximum breadth about 50 per cent. of or slightly more than 50 per cent. of combined length of stalk and eye. Cornea black, indistinctly bilobed, with the maximum breadth of the cornea in a dorsolateral direction being about one third maximum length. Inner margins of the eyestalks in juxtaposition for about half their length, thereafter diverging quite strongly (in this last respect, they resemble those of *S. latreilli* (Eydoux and Souleyet) sec Serène, 1952, Pl. I, Fig. 1 and *S. decorata* (Wood-Mason) sec Kemp, 1913, Pl. I, Fig. 13).

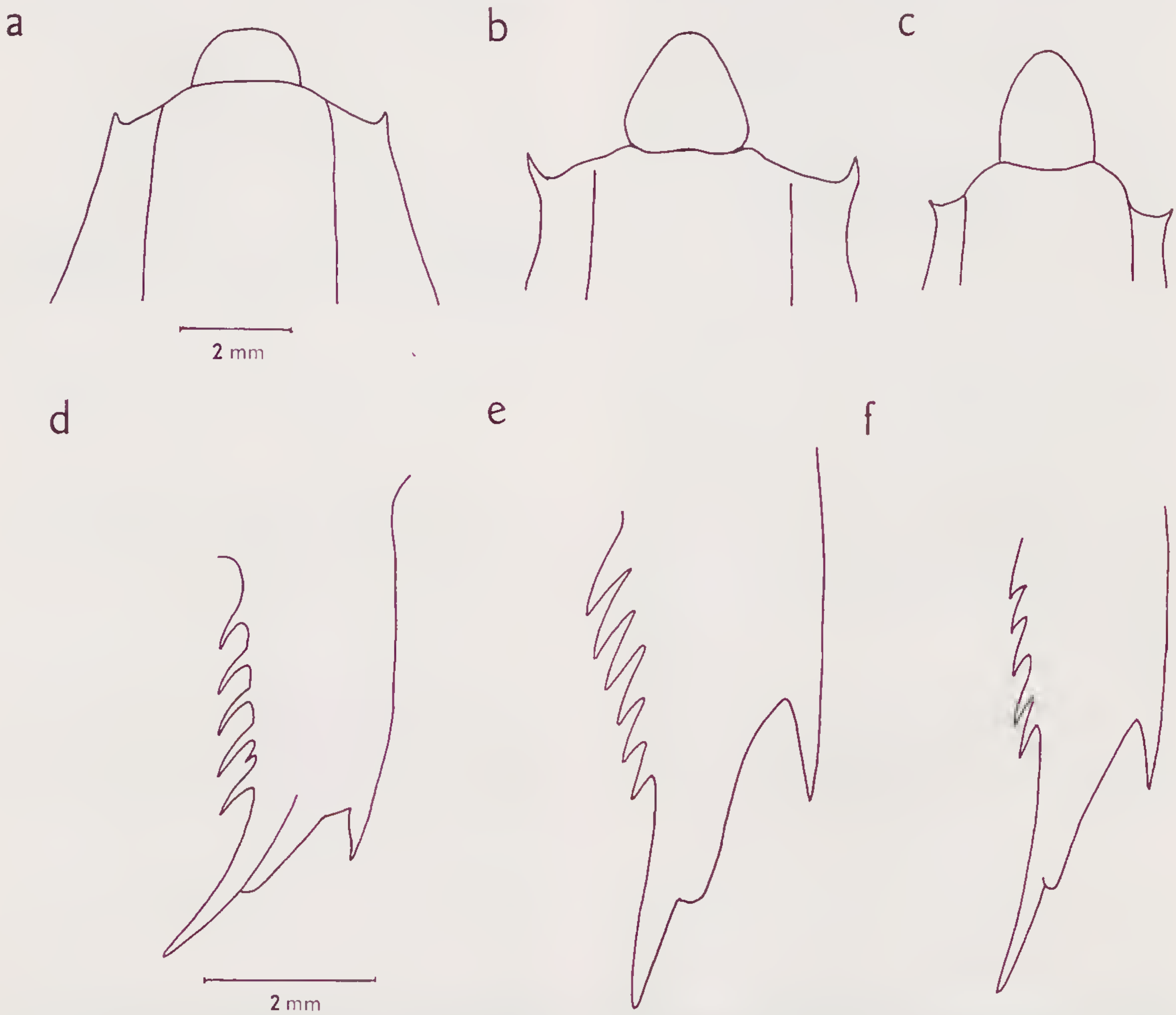

Fig. 2.—*Squilla microphthalma*—a, b, c.—Rostrum and anterior part of carapace; a, 39 mm specimen; b, after de Man (1898); c, after Serène (1952). d, e, f.—Bifurcate process of uropod; d, 32 mm specimen; e, after Kemp (1913); f, after Serène (1952).

Antennules.—Peduncle approximately two-thirds the combined lengths of the carapace and rostrum.

Antennae.—Basal segment together with proximal segment of exopodite slightly shorter than the length of the distal segment (scale) but not reaching to the middle of the eyes. Peduncle of endopodite c. 1.4 times the length of the antennal scale (excluding bristles) and equal to or slightly longer than the anterior breadth of the carapace.

Mandibular palp.—Present, three segmented in all but the smallest specimen, here apparently two segmented.

Rostrum.—Semi-elliptical (length about 60 per cent. of breadth) to semi-circular.

Carapace.—Maximum breadth slightly less than the length (excluding the rostrum) and double the minimum breadth behind the antero-lateral angles. Anterior borders between the rostrum and the anterolateral angles distinctly inclined posteriorly. Anterolateral angles each with a well-developed spine. Lateral borders straight in their anterior three-quarters, with smoothly rounded posterior angles and smoothly concave posterior border.

Cervical groove distinct, gastric groove distinct anterior to the cervical groove, but less distinct posterior to it. No trace of median, intermediate or lateral carinae, nor of marginal carinae anterior to the cervical groove. Posterior to cervical groove, marginal carinae distinct and best developed in their reflected portions. A pit present in the mid-line of the carapace about one third of the way backwards from the anterior margin. A mid-dorsal tubercle just in front of the posterior margin of the carapace.

Raptorial claws.—Articulation of ischium and merus not terminal, but slightly in advance of the proximal end of the latter. Merus massive, with concave inferior margin. Upper margin of the carpus with a single distinct curved carina running along three-quarters of its length and terminating abruptly; near the termination there is a tuft of setae. Propodus deep and swollen, bulging particularly at its carpal articulation, and with a smoothly curved lower margin. Upper margin pectinate, with setae amongst the teeth and there are the usual three stout movable spines just inside the proximal part of the upper margin. Dactylus with four spines, the terminal one being much the longest. The lower margin of the dactylus is sinuous.

Thoracic somites.—Fifth somite bearing on each side a lobe (often blunted, but acute in largest specimen) which continues ventrally as a short ridge. Sixth, seventh and eight somites bearing distinct but rounded intermediate carinae; the lateral margins carinate. No median or submedian carinae on the thoracic somites.

Sixth and seventh somites with entire and rounded borders. Lateral margin of eighth somite partly covered by a bluntly rounded anterior projection from the first abdominal somite. Endopodites of the last three thoracic appendages elongated ovoids.

Abdominal somites.—First five somites bearing distinct intermediate, lateral and marginal carinae but median and submedian carinae not present. On the sixth somite, there are submedian, intermediate, lateral and marginal carinae, the last two converging posteriorly. The following carinae end in spines, brackets indicating absence in some of the specimens:—

Carinae	Abdominal somites
Submedian	6
Intermediate	(5), 6
Lateral	—
Marginal	(4), 5, 6

Termination of marginal carina of fourth abdominal somite rarely sharp enough to be termed a "spine"; that of third somite even less spiniform.

Telson.—Broader than long (c. 1.6 times) and strongly convex. Median carina very distinct and ending in a distinct spine. A row of tubercles on each side of the carina, these rows being referred to below as submedian tubercles. Up to five tubercles present, being sometimes distinctly separate and sometimes more or less fused. The most anterior on each side comprises a broad elevated area and behind these the rows converge, sometimes terminating in a median tubercle behind the carina. Between these submedian tubercles and the marginal teeth of the telson, there are 2-4 (typically 3) obliquely pointing and elevated rounded ridges (or elongated tubercles). Up to three pairs of additional tubercles towards the margins of the telson, representing basal inflations of the carinae of submedian and intermediate teeth respectively and lying near the base of the lateral teeth. In the smallest specimen only the submedian inflations are present.

Margins of the telson ornamented as follows:—a pair of blunt submedian teeth with movable spines; between these there are 3-4 (typically 4) pairs of denticles; a pair of stout but sharp intermediate teeth separated from the submedians by 6-8 denticles on each side; and a pair of acute sharp lateral teeth separated from the intermediates by a single denticle on each side. Anterior two-fifths of margin of lateral tooth of telson with a stouter carina than the remainder which, in the large specimens, terminate in an inconspicuous prelateral denticle. As stated above the carinae of submedian and intermediate teeth are represented in the larger specimens by tuberculate carinae. These sometimes show indications of being composed of fused rows of smaller tubercles.

Under surface of the telson microscopically granular, and without a post-anal carina.

Uropods.—Bifurcated process of basal segment armed internally with 5-7 (typically 6) sharp, elongate teeth. Longer process about thrice the length of the shorter and with a basal thickening on the margin facing the shorter process. Thickened portion very conspicuous and sinuously curved.

External margin of the basal segment of the uropod bearing 5-6 (typically 6) articulating spines, the terminal much the largest. The terminal segment of the exopodite approximately $2\frac{1}{2}$ times as long as broad.

Colours after prolonged alcohol fixation:—General colour of larger speciments biscuit, but raptorial claws ivory coloured. Typically with numerous black or sooty brown pigmented areas of which the most conspicuous arc:—(a) rostrum and anterior carapace (see Pl. I, Fig. E); (b) posterior carapace where a black line near the border continues in the anterior reflections of the marginal carinae; (c) on most of the free thoracic somites and abdominal somites where transverse lines occur near the posterior margin of each. These lines are absent on the fifth thoracic somite and typically on the sixth abdominal somite and are feebly developed on the fifth abdominal somite. There is a small black spot in the posterior medial portion of the penultimate segment of the exopodite of the uropod.

In the smallest specimen the cnly pigmented portion apart from the cornea consists of small dark spots near the anterolateral margins of the carapace, while in the 28 mm specimen, the first five abdominal somites bear additional diffuse spots of pigment running across each segment, and the sixth abdominal somite is pigmented as in the previous ones.

Comments

In the four individuals differences in the densities of pigmentation and the ornamentation of the telson are within the expected range of variation of a species. However the smallest specimen differs in further particulars:—(a) less curvature on the inner margins of each eyestalk; (b) in dorsal view eyestalks extending relatively forward in relation to the basal segment of the antennular peduncle. Only about one-eighth of the length of this segment projects forward beyond the eye, and (c) mandibular palp. This is proportionally smaller than in the remaining specimens, and although apparently undamaged, only two segments could be distinguished instead of three.

The species was previously known from Zanzibar, India, Indo-China and Indonesia but not from Australia.

Acknowledgments

Thanks are due to (a) the Directors of the following Museums for loan of specimens:—Western Australian Museum (Dr. W. D. L. Ride) Australian Museum (Dr. J. W. Evans), Macleay Museum, University of Sydney (Miss E. Hahn); (b) the Curators of the crustacean collections at the first two Museums (Dr. R. George and Mr. F. A. McNeill) who have been especially helpful; (c) the following Directors or Curators in New Zealand Museums for forwarding specimens of *Lysiosquilla*—Professors J. Morton, G. Knox, L. R. Richardson; Drs. R. Falla, R. R. Forster and Mr. R. W. Macdonald; and (d) to Dr. A. A. Racek for specimens and information on *Squilla mcneilli* and to Mr. L. Wale for a specimen of *Lysiosquilla latifrons brazieri;* (e) Miss May Rees for assistance throughout and especially in preparing line drawings; and (f) to the Research Committee of the University of Queensland for financial support.

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6.—Larks, Mirafra javanica, of tropical Western Australia

By G. F. Mees*

Manuscript received—20th February, 1962

On the basis of freshly collected material the distribution and geographical variation of *Mirafra javanica* in Western Australia is discussed in greater detail than was possible by Mayr & McEvey (1960), to whose paper the present one may be regarded as complementary.

Introduction

In their important paper on distribution and geographical variation of *Mirafra javanica*, Mayr & McEvey (1960) suggested further field studies. They also discussed the application of ternary nomenclature in the species and some other matters.

From May till August, 1960, my assistant, Mr. A. M. Douglas, and I visited the northern part of Western Australia. We paid special attention to *Mirafra*, and collected 39 specimens, many of which are from localities whence the species had not previously been recorded. This resulted in a much improved knowledge of the distribution of the various colour-types, including the discovery of a very rufous population in the Kimberley Division. I have thus been able to extend the information given by Mayr & McEvey and to discuss some of the questions raised in their stimulating paper.

The first draft of this paper was sent to Dr. Mayr and Mr. McEvey, to both of whom I am indebted for useful comment and criticism, much of which has been incorporated. I have to thank Dr. D. Amadon (American Museum of Natural History) for the loan of four topotypical specimens of *Mirafra javanica melvillensis*. Mr. R. Vollprecht, of the Perth Weather Bureau provided me with the 1960 rainfall figures for Wyndham. Finally Mr. Douglas and I want to express our sincere gratitude to the many friends whose hospitality contributed so much to the success of our stay in the Kimberley Division.

Distribution, Habitat and Habitat Preference

Mirafra javanica is widely distributed in the North-West Division from Minilya northwards, and in the Kimberley Division (Fig. 1), and there is no doubt that its distribution is continuous or nearly so. The occurrence seems to be governed by the presence of seeding soft grasses, the seeds of which are (at least in the months May till August over which my experience extends) its main and perhaps its only food. In stomachs I found exclusively seeds of at least two different species of grasses, though unfortunately these were not preserved for identification.

In the Kimberley Division, larks occur not only in the open fields and paddocks with rather low and small soft grasses, but also in the very high *Heteropogon contortus* in open savannah; usually, however, as solitary specimens, never in great numbers, and never in the denser types of savannah-woodland.

The preceding notes on habitat do not conflict with my earlier statement that the distribution of the species is continuous or nearly so, for open savannah and open fields are so common in the Kimberley Division that for practical purposes they may be regarded as a continuous habitat. This is supported by the fact that at every place visited by us in the Kimberley Division we found larks. It may be noted that Mayr & McEvey (p. 163, 164) do not seem to be quite clear about the position. They loosely use the word "isolates" for several of the populations, but contradict this by saying ". . . . . . that *subrufescens* . . . . . is essentially an inland race tending to intergrade with the coastal isolates around it in the west". Mr. McEvcy wrote me that the term "isolates" was partly used as a substitute for "subspecies", mainly to avoid continuous repetition of the words subspecies and race. Personally I would prefer not to water down the term isolate as this is likely to cause confusion.

Wherever I observed larks, I have made notes on the colour of the soil, and feel justified in stating—contrary to what is said of certain species of larks in Arabia and the Kalahari Desert—that they show no particular preference for soils corresponding in colour with the colour of their own plumage. When going to alight, the birds are clearly guided exclusively by the presence of seed-bearing grasses, quite irrespective of the colour of the soil.

This does not mean, however, that any idea of correlation between colour of soil and colour of larks should be abandoned. In much of the Kimberley Division the rocks are of a reddish-brown colour, consisting of reddish sandstone and red weathered basalt. All true plains, on the contrary, have a greyish-yellow colour. At Beverley Springs and Kalumburu, though some of the paddocks where one finds the greatest concentration of larks are greyish-yellow, the country is hilly so that the greater part of it is reddish-brown in colour—and so are the larks in these places. Going from Beverley Springs over Mount House to Glenroy, the larks become slightly paler in colour. But Glenroy is an enormous plain. At Wyndham the hills consist of red sandstone and their erosion products are just as red as the reddish-brown sand found in localities where rust-coloured larks occur. However, the most conspicuous feature of the country near Wyndham are the extensive grey flats, the estuarine plains of several rivers, and it is to that colour that the larks are adapted. As a generalisation, therefore, I would say that

* Western Australian Museum, Perth, Western Australia.

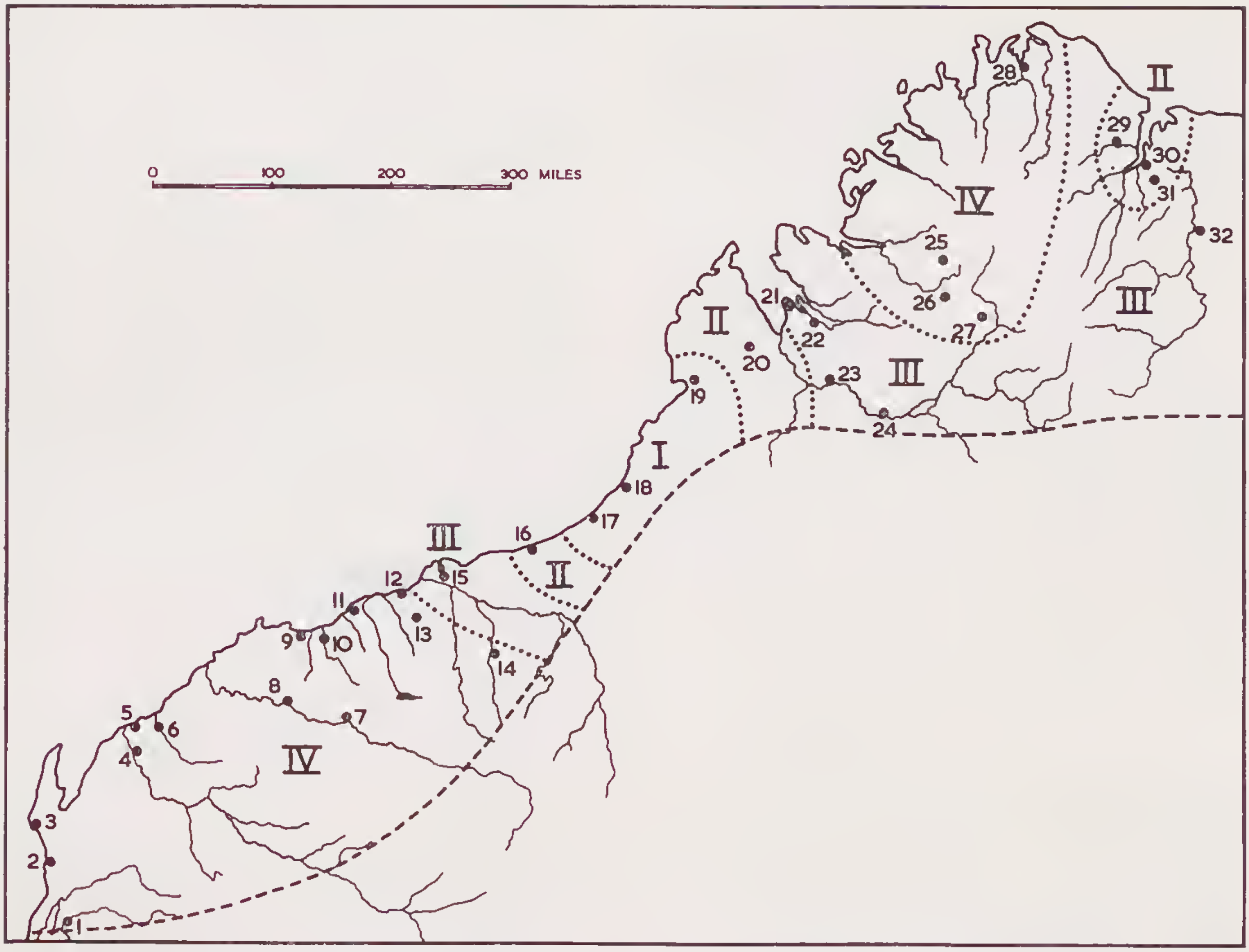

Fig. 1.—The distribution of *Mirafra javanica* and its colour types in Western Australia. Localities: 1, Minilya, 2, Maud's Landing; 3, Point Cloates; 4, Minderoo; 5, Onslow; 6, Cane River; 7, Coolawanyah; 8, Millstream; 9, 14 miles east of Roebourne; 10, Sherlock; 11, Mundabullangana; 12, Port Hedland; 13, Tabba Tabba; 14, Marble Bar; 15, De Grey; 16, Pardoo Sands, 116 mile peg; 17, Wallal, 30 miles beyond homestead; 18, Anna Plains Outcamp; 19, Roebuck Bay Plains, Broome; 20 Broome-Derby Road, 85 and 88 mile pegs; 21, Point Torment; 22, Meda; 23, Liveringa; 24, Noonkanbah; 25, Beverley Springs; 26, Mount House; 27, Glenroy; 28, Kalumburu; 29, Forrest River; 30, Wyndham; 31, Parry's Creek; 32, Argyle (Ord River).

in hilly or mountainous areas rusty coloured larks may be expected, in lowlands yellowish-grey larks. The very rufous *M. j. woodwardi* of the hilly North-West, and the pale *M. j. halli* of the plains near Broome, further support this assumption.

In view of the extreme paleness of the race *halli*, special attention was paid to the colour of the soil in its range. The coastal area along the Eighty Mile Beach where we found and collected larks consists of pale yellow dune sand. Near Broome the coastal strip is also pale, but it does not extend far inland and patches of brownish and reddish soil occur very near the town as I could ascertain when flying over the area. This suggests that along the Eighty Mile Beach the species does not range far inland, but is confined to the pale coastal strip. The coastal sands south-west of Port Hedland (Mundabullangana) are just as pale as those near Broome, but the larks there have behind them the great reservoir of rufous larks from the hilly Pilbara District so that any local selective influence would be undone.

Dr. Mayr has pointed out to me that the situation in Australia is probably not directly comparable with that in Africa, as there the contrast between the substrates is exceedingly great. Rich red rocks will meet along a geological fault line almost snow white limestones. Elsewhere, black lava flows will meet whitish sands. The differences in soil colour found in the north of Western Australia are certainly far less striking. Nevertheless it is worth pointing out that in Australia no preference for soils which correspond in colour with the plumage of the birds seems to have developed, and in fact, this is one of the questions posed by Mayr & McEvey.

Mayr & McEvey (p. 190) enquire about the possible significance of habitat colour (general colour of a paddock of seeding grasses) as opposed to ground colour. As far as I have been able to make out, this colour, which in the seeding season is pale yellow, has had no influence as a factor contributing to the colour of the birds. This is not surprising when one considers the fact that *Mirafra javanica* is essen-

tially a ground bird, so that cryptic coloration, to be of any advantage, has to agree with the colour of the ground, rather than with that of its vegetation. Moreover, habitat colour is presumably identical in all parts of the range (though seasonal variation from green to yellow probably occurs), and if it has any effect, this will be difficult to detect because it would work in exactly the same way throughout the range. Also there seems to be a preference for small open places or places with scanty vegetation—more about this in the section on behaviour.

Miscellaneous Notes on Behaviour, etc.

Towards the end of July, 1958, I found the larks at Millstream and Coolawanyah stations in full song. Early that month there had been heavy rainfall in the district and during the last days of the month more rain fell; I mention this because of the possibility that sexual activity is stimulated by rainfall, as has been shown in other Australian bird-species (cf. Keast 1959). Some notes on the behaviour of the birds during rain were published previously (Mees 1961).

During our trip, we did not hear any song until on my last day of field work in Wyndham, July 31, 1960, when one or two birds were in full song. This evidently was the first song of the season because for a week I had been visiting the same localities almost daily, and had not heard any song. Rainfall in Wyndham during 1960 was: January 897 pts., February 814, March 928, April 223, May 347, June till October nil, November 250, December 460.

Apart from the singing birds in Wyndham, the only noise I heard from larks in the period May-July 1960 was a short double note uttered in flight: "pitpit . . . . pitpit . . . . .".

When preparing specimens collected I have taken notes on size of gonads, state of ossification of skulls, and condition of moult, the results of which are tabulated. In all specimens of which the sex could be determined the gonads are small to very small; this is particularly striking in the males, for in adult females the normal size of a resting ovary is apparently about 5 mm, which is fairly large; but none of the females had enlarged oocytes. In the specimens of uncertain sex, the gonads were pre-

TABLE I

Locality	Date	Sex	Gonads	Ossification skull	Moult
14 miles N. of Roebourne	22.V.1960	♂	small, 2 mm.	fully ossified	body feathers
,, ,,	..	♀	...	fully ossified	body feathers and tail
Mundabullangana	23.V.1960	♀ juv.?	?	partly ossified	no moult
Pardoo Sands	25.V.1960	♀	very small, 2½ mm.	....	....
,, ,, ...	..	? imm.	....	partly ossified	....
Broome - Derby Road, 85-mile peg	1.VI.1960	?	....	fully ossified	moult
Broome - Derby Road, 88-mile peg	1.VI.1960	♂	tiny, less than 1 mm.	largely unossified	moult
Kalumburu	14.VI.1960	? imm.	....	partly ossified	heavy moult
,, ...	2.VII.1960	♀ imm.	tiny, 3 mm.	....	....
,, ...	1.VII.1960	♀ ad.	fairly large, 6 mm.	fully ossified	primaries, no moult in body feathers
,, ...	24.VI.1960	♂	small, 1½ mm.	fully ossified	heavy moult primaries
,, ...	19.VI.1960	♀ ad.	fairly large, 6 mm.	fully ossified	wings
,, ...	27.VI.1960	♂	small, 1 mm.	fully ossified	primaries and rectrices
,, ...	12.VI.1960	♂	fairly large, l. testis 3½ mm., r. testis 2½ mm.	fully ossified	....
,, ...	14.VI.1960	? imm.	...	partly ossified	heavy moult
,, ...	24.VI.1960	♂	small, 1 mm.	fully ossified	wings
Beverley Springs	19.VII.1960	♀	fairly small, 5 mm.	not completely ossified	....
,, ,,	..	♂	tiny, less than 1 mm.	fully ossified	....
,, ,,	11.VII.1960	♀	fairly small, 3½ mm.	fully ossified	....
,, ,,	19.VII.1960	♂	small, 1½ mm.	fully ossified	....
,, ,,	13.VII.1960	♀	fairly small, 4½ mm.	fully ossified	....
Wyndham	25.VII.1960	♀	fairly small, 4½ mm.	fully ossified	....
,, ...	31.VII.1960	♀	fairly small, 5 mm.	fully ossified	body feathers, heavy tail moult
,, ...	25.VII.1960	♂	small, 1 mm.	fully ossified	....
,, ...	26.VII.1960	♂	fairly small, 2 and 2½ mm.	fully ossified	....
,, ...	28.VII.1960	?	....	fully ossified	
,, ...	25.VII.1960	♀ imm.	small, 4 mm.	partly ossified	....
,, ...	28.VII.1960	♀	fairly small, 5 mm	fully ossified	....
,, ...	26.VII.1960	♀	fairly small, 5 mm.	fully ossified	....

sumably so small and inconspicuous that they could not be found. Unfortunately I failed to obtain a singing bird at Wyndham; it would have been interesting to compare the size of its gonads with those of non-singing birds. My observations fit in with McEvey's (1960) statement that the only months in which breeding of *Mirafra javanica* in Australia has not been recorded are May, June, July and August.

Many of the specimens show moult. Examination of the condition of ossification (or pneumatisation) of the skull enabled me to check whether the plumage characters hesitatingly claimed by Mayr & McEvey (p. 156-157) to be diagnostic of young birds, do hold. I found that the character of the pale edges to the crown feathers, which gives the crown a more or less scaly appearance, is apparently a valid one. As regards the outer edges of the primaries, allegedly wider in young birds, there is certainly a tendency to this, but the difference is not very convincing.

The way to observe larks is to walk criss-cross over likely-looking country (e.g., places covered with soft grasses) until one is flushed. The flight is slow and with characteristic fairly short wing-beats. Usually they alight nearby. The birds are to be found on small open or less densely covered places, rather than in the densest grassland. This probably is also the reason that quite often we found them near cattle—where the vegetation had been trampled down.

Partly this preference for certain places may be responsible for the concentration of birds one often sees in a very limited area, but on the other hand larks are definitely social. Not only did I observe repeatedly how flying larks joined each other, or would even be joined by those that had been standing on the ground, but also when a number were flying about at a time, and one alighted, others would alter their course and alight near the first individual.

There is no doubt that when not in song the birds are rather inconspicuous. When singing they inevitably make their presence known widely. When not singing, however, they stick to the ground, and will not fly up until disturbed. Hence, the casual observer may easily overlook them even in paddocks where they are common.

Several authors, of which Bourke (1947) may be mentioned in particular, have drawn attention to the amount of mimicry in the song of *Mirafra javanica;* Bourke even states: ". . . . that mimicry forms the bird's 'normal' song during the breeding season, and that from February until September (approximately) the song of the species consists of a short double note—merely a call-note". This call-note is evidently identical with the one described by me on a previous page—in my opinion it is incorrect to call it song. As regards the song, Bourke is certainly right that much of it consists of imitation, but the statement that mimicry *forms* the song definitely goes too far.

I have no notes on mimicry in Australia, but did hear it from the nominate race, *Mirafra javanica javanica* Horsfield, in Java. For example, on 29.VI.1947 near Buitenzorg, West Java, I noted that there was apparently much mimicry in the song, and that the ordinary call of *Pycnonotus aurigaster* (Vieillot) could easily be recognised in it. Another time I recognised the call of *Caprimulgus affinis* Horsfield and the song of *Prinia inornata blythi* (Bonaparte), both imitated almost perfectly (Tjibarocsa, West Java, 2.VII.1949).

Geographical Variation

The colour varies from rufous to white on under-parts, and from black to grey, with the edges of the feathers varying from rufous to white, on the dorsal surface. In the Northern Territory there is a population (*söderbergi*) with a very black back, and little rufous, but in Western Australia the black-grey seems to be more or less correlated with the rufous-white series, and does therefore not need a separate discussion. I distinguish the following colour types:—

(i) No rufous at all except some pale brown along the outer edges of the primaries; under surface creamy white; back grey. The white extreme.

(ii) As (i), but a very slight admixture of brownish on the back; under surface cream.

(iii) More brownish than (ii) both above and below.

(iv) All the feathers of the dorsal surface with dark rufous borders, under surface cinnamon. The rufous extreme.

In Fig. 1 I have tried to indicate the approximate ranges of these four colour types in Western Australia. The figure also shows very clearly the difficulties of practical classification one encounters when trying to deal with these populations trinomially. Going from Roebourne along the Pardoo Sands to Anna Plains, one covers the whole zone of intergradation between the rufous *woodwardi* and the pale *halli;* from Broome going north-east via Derby to Beverley Springs one encounters the same gradual change in opposite direction, from *halli* to *melvillensis*.

The three races mentioned, *woodwardi, halli* and *melvillensis* are extremes, hence there is no problem in applying trinomials. We come now to colour type (ii) however. This is at Pardoo Sands and between Broome and Derby merely an intermediate—or a product of intergradation—between (i) and (iii) which, for practical purposes, should not be named*. Near Wyndham, on the other hand, an indistinguishable population occurs which is not an intermediate, but forms the end of a gradient of a decreasing amount of rufous in the plumage.

* Admittedly the Pardoo Sands at the 116 mile peg, where we collected larks of an intermediate coloration, are a pinkish mixture of the red sand of the interior with the whitish sand of the dunes; hence one might argue that the larks at this locality are intermediates because they live on a soil of intermediate coloration, and not because of their intermediate geographical position between *woodwardi* and *halli*.

At the 85 and 88 mile pegs on the Broome-Derby Road, where intermediate larks were collected, the soil is pale yellowish with a pink tinge due to a very slight admixture of red sand.

To colour type (iii) the same pertains as to colour type (ii); it is another intermediate: between Roebourne and Pardoo Sands and near Derby a product of intergradation between (iv) (*woodwardi*) and (ii), but at Argyle perhaps an extreme in the rufous direction as no more rufous population is yet known to exist near that place (it is very well possible that the range of the *melvillensis*-like population extends in an easterly direction to south of Wyndham, but no material is yet available).

It must be realised that my division of the larks in four colour types (as far as amount of rufous in the plumage is concerned) is purely arbitrary. With equal justice I might have divided them in six or eight types. Also as far as my experience goes, the gradients are perfect: the boundaries indicated between the various colour types again are arbitrary which means that specimens here ascribed to (ii) which have been collected near the range of (i) are pale, whereas specimens nearer to (iii) are more rufous.

Fig. 2.—Grass plains at the 85 mile peg on the Broome-Derby Road, habitat of *Mirafra javanica* subsp. (colour group II). 1. VI. 1960.

Fig. 3.—Grass plains at Beverley Springs, habitat of *Mirafra javanica melvillensis*. 19. VII. 1960.

Colour type (iii) corresponds to what Mayr & McEvey call *subrufescens*, a race they give a continuous range from the De Grey River area in the west to the Gulf of Carpentaria in the east. At De Grey it appears as an intermediate between *woodwardi* and *halli*, near Derby as an intermediate between *halli* and *melvillensis*, west of Forrest River it remains to be discovered as an intermediate between "*forresti*" and *melvillensis*, south of Wyndham (Argyle Downs) it may occur as a soil-adapted population of its own accord, not as an intermediate. It looks as if Mayr & McEvey's *subrufescens* is not the widely-ranging subspecies these two authors thought it to be, but consists of a series of geographically unconnected populations, each of which has a different history.

Some Principles of Nomenclature

Mayr & McEvey, discussing the geographical variation of *Mirafra javanica*, correctly stress the fact: "that it is quite impossible to express this complex variability adequately in terms of orthodox subspecies". It is perhaps right to state that I am a strong believer in the ternary system of nomenclature, and the fact that it is sometimes inadequate does not in my opinion mean that the whole ternary system must be rejected. I would even go farther and say that Linnean nomenclature, with its present-day implications of relationships, is only useful when one clearly realises that classification, which inevitably is limited to a small number of systematic categories, is of necessity arbitrary, even though we may call it a natural system. Our whole knowledge of speciation and evolution confirms that there are all stages of intermediates between our artificial classes, and that, indeed, no two pairs of species or other systematic categories stand in exactly the same relation to each other. Once this is clearly recognised, Linnean nomenclature can be used with much advantage.

Mayr & McEvey have named populations, even though very similar populations might occur in other parts of the range of the species, a method they defend as follows (p. 188): "Mention has been made of the inadequacy of orthodox nomenclature . . . . . and it is merely added here that their treatment will partly depend upon whether one looks at them from the viewpoint of the taxonomist or the student of evolution. To the taxonomist identical populations (i.e., polytopic subspecies) must be given the same name. To the student such a terminology would seem to obscure the fact of the independent evolution obviously involved". However, they add: "In the present cases the majority of individuals in a given race are distinguishable from the majority in the parallel form". As our whole system of nomenclature is based on morphology, it would, indeed, be undesirable to abandon the generally accepted provision that a form, to deserve a place in nomenclature, must be morphologically recognisable.

It seems to me that nomenclature tends to take too important a place in many systematic publications. Systematic ornithology should be concerned with the description of actual variation as found in nature, rather than with the

PLATE I (opposite)

Upper figure, *Mirafra javanica halli*, after a specimen from Anna Plains Outcamp. Lower figure, *Mirafra javanica melvillensis*, after a specimen from Kalumburu. Figures of approximately natural size.

subsidiary problem of how to apply trinomials, which is not a biological problem at all, but largely a matter of tidyness of the human mind.

The geographical variation in most species of birds, especially where island populations and other discontinuities in distribution are concerned, can be conveniently and profitably expressed in trinomials. In *Mirafra javanica* we have a species that shows a strong geographical variation (in the concluding section more evidence for this variation being truly geographical and genetic will be brought forward), but the peculiar nature of these variations causes the application of trinomials to be of little use, if not actually misleading. Nevertheless, to be consistent with the treatment of other bird species rather than for any other reason it seems undesirable to reject all use of trinomials.

The tentative solution offered in the following chapter is, as I realise full well, a half hearted attempt at a compromise that may not satisfy anybody but that should be acceptable until an entirely new approach to the problem may be made.

Nomenclature to be applied in Western Australia

It is possible, and desirable, to name extremes, in other words populations that cannot be considered to be intermediates or products of intergradations. On the basis of this, the following trinomials can be applied in Western Australia.

1. *Mirafra javanica woodwardi* Milligan, type locality Onslow. Synonym: *Mirafra javanica subrufescens* Mathews. Very rufous, and reduced spotting on the throat. Inhabits the North-West Division of the State, and intergrades north-east of Port Hedland with the following species.

Mayr & McEvey (p. 161) specify the type locality of *subrufescens* as being "Tabba Tabba, N.W. Aust. (south of Fitzroy River)", which is doubtless true, but rather misleading, for Tabba Tabba is actually about 15 miles south of Strelley and about 30 miles south-east of Port Hedland, so that the type locality of *subrufescens* is not, as Mayr & McEvey suggest, in the Kimberley Division, but in Pilbara, and four hundred miles away from the nearest point of the Fitzroy River. Birds from this locality are only slightly paler than true *woodwardi* and can be included in that race without distorting the facts. Correspondence has revealed that both Mayr and McEvey were under the misapprehension that Tabba Tabba was in the Kimberley Division, and that in applying the name *subrufescens* they have been partly misguided by their incorrect idea of the geographical position of its type locality. Certainly the birds of my group (iii) in the Kimberley Division, where they range widely, have a better claim to nomenclatorial recognition than the intermediates of the Port Hedland area. If a separate subspecific name is to be given to the birds of this group, a new one would have to be provided.

Specimens from Millstream and Coolawanyah about which Mayr & McEvey received notes from me, were referred by these authors to *subrufescens*. On the other hand I found that these specimens agree very well with the type of *woodwardi* which is in the collection of the Western Australian Museum (Mees 1961). Actually the type of *woodwardi* comes from very near to what according to Mayr & McEvey is an area of intergradation between *woodwardi* and *subrufescens*. If a type specimen is intermediate between two races, the name will have to be restricted to one of the components. Yet, I cannot agree that specimens identical with the type of *woodwardi* should be called *subrufescens* (it is not a single individual I am discussing but a series of five, which is presumably more or less representative of the populations of Millstream and Coolawanyah). Actually this supports my opinion that *subrufescens* must be synonymised with *woodwardi*.

2. *Mirafra javanica halli* Bianchi, type locality Roebuck Bay Plains near Broome (Plate I, upper figure). The palest of all races, no brown in plumage except on edges of primaries and secondaries. Coastal plains from Broome to Wallal. Intergrades at Pardoo Sands with the preceding subspecies and near Derby with the following.

3. *Mirafra javanica melvillensis* Mathews, type locality Melville Island (Plate I, lower figure). As dark rufous as *woodwardi*, but on an average more blackish above, throat spotting heavier. Distribution, Melville Island and the north-western part of the Kimberley Division. It is not suggested that there is any historical or zoogeographical significance in the similarity of the Melville Island and north-west Kimberley populations, but I have been unable to find any morphological character to distinguish them from each other, except that the Kimberley birds average very slightly paler below.

Also valid is the name *söderbergi* for specimens from the northern part of the Northern Territory, which have the unique combination of very little brown with a strongly blackish tinged upper surface. Contrary to Mayr & McEvey I prefer not to apply a trinomial to the population from near Wyndham (*Mirafra javanica forresti* Mayr & McEvey) because identical specimens occur as intergrades elsewhere.

Incidentally, Mayr & McEvey (p. 167) described "*forresti*" from Forrest River and Parry's Creek, but included a specimen from Wyndham in "*subrufescens*". This is most unlikely because Wyndham is between Forrest River and Parry's Creek, and the latter locality is only 15 miles south of Wyndham, and on the road to Argyle Downs where "*subrufescens*" occurs. The specimens collected by me at Wyndham all are much paler than material from Argyle Downs, and evidently are typical "*forresti*". The most likely explanation seems to me that Mayr & McEvey's specimen labelled Wyndham was actually collected somewhere inland from Wyndham in a time that the need of exact labelling was perhaps less strongly felt than nowadays.*

* I have now received this specimen, a flat skin, on loan from Mr. McEvey. It was collected on July 30, 1959, in a grass and rock habitat on Wyndham Airfield by Dr. G. Brown, hence there is no doubt about its locality of provenance. Curiously this bird is, as Mayr & McEvey correctly state, far browner than "*forresti*" and than any of the birds I saw near Wyndham. It may be a straggler from a different area, and it certainly shows that much fieldwork and collecting remains to be done.

Mayr & McEvey (p. 167) state that their race "*forresti*" is confined, so far as is known, to the Forrest River/Parry's Creek area, but add a few lines lower down that specimens from Point Torment, Derby, Meda, and Lennard River are referable to the same subspecies. Even so, as their map shows, Mayr & McEvey were able to give their new race a continuous range throughout the northern Kimberley Division. The discovery of *melvillensis* in this area has broken up the continuous range ascribed to "*forresti*", which is one of my reasons for rejecting the name.

A special nomenclatural difficulty lies in the fact that the oldest name given to an Australian bird, *horsfieldii*, apparently applies to an intermediate population. Fortunately this is outside the area covered by this paper. It is likely that no final classification can be arrived at without a study of the genus *Mirafra* as a whole.

Historical Considerations and Evidence Against Migration

Throughout this paper it has been taken for granted that the variation in colour is genotypic in character; this notwithstanding the fact that Mayr & McEvey found one population (the "Atherton substrate type") where the coloration is apparently largely caused by stain. I have found no evidence of this in Western Australia. The possibility that colour might be an extremely variable character, and that perhaps a bird might be able to assume a plumage of the colour of the soil it happens to be living on at the time of moult can also be ruled out for various reasons. One is that specimens kept in captivity in Perth for some years did not change colour. The most important reason is that wherever I observed and collected larks in any one locality (and at some places, like Wyndham and Beverley Springs I observed large numbers) all birds were remarkably uniform in colour. The individual variation in any one locality is only very slight—which certainly indicates that the colour is genetically fixed. Contrary to Mayr & McEvey (p. 159) I failed to find indications of increased variability where strongly different forms approach each other geographically.

Another point is that in Western Australia there are nowhere abrupt changes from one colour type into another. Everywhere, as far as is known, smooth intergradation occurs. And though for example along the Eighty Mile Beach it is very striking how, over the comparatively small distance of two hundred miles, the colour changes from the deep-rufous *woodwardi* to the pale *halli*, even here the change is smooth and gradual.

A complicated pattern of distribution as the present one, of populations that are uniform in any one locality and are doubtless truly genetical, can only be explained by assuming that the birds are everywhere in their range extremely sedentary. The geographic variations being as they are, in many localities a bird only a hundred miles away from its place of birth would be conspicuous. No such aberrant individuals have yet been found, though they are almost certain to turn up when very large series are collected. Mayr & McEvey (p. 178, 179) mention some aberrant birds from the range of *horsfieldii*, but the position in south-eastern Australia is probably different as set forth below.

Another possibility, that the birds would migrate in winter but return to their place of birth in the breeding season, can be ruled out for the same reason as given above: in the period from May to August, the only months in which no breeding is known to occur (McEvey 1960), not a single aberrant bird that might be regarded as a migrant of a population different from the local one was noted. It is also difficult to see how selection for soil colour could take place in such a case.

The preceding notes can be taken as evidence against the occurrence of seasonal movements in Western Australia, a point about which Mayr & McEvey (p. 189) enquire. It is perhaps significant that the race *horsfieldii*, the only one in which substantiated evidence of seasonal movements exists, has a wide distribution and is according to Mayr & McEvey more or less uniform over its whole range.

Finally, I want to express my agreement with Mayr & McEvey's thesis (p. 155): "This single selection force, colour of the substrate, seems to over-ride all others". It is remarkable that this should be so, particularly because—as shown on a previous page—no active preference seems to have developed with it. Anyway, there is no doubt that *Mirafra javanica* is a highly successful species in Western Australia, that occurs wherever suitable habitat is present. Contrary to most other forms of wild life it may even look forward to a rosy future, for man's activities, like stocking remote areas, are likely to increase rather than decrease the extent of its habitat.

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7.—Land Forms and Soils in the Avon Valley, near York, Western Australia

By R. L. Wright*

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Four stages of downcutting and base-levelling are recognised between a deeply weathered surface and the main channel in part of the Avon valley, Western Australia. Corresponding to the first three stages are two rock-cut terraces and a double phase alluvial terrace. The fourth stage is represented by a later incision of the Avon and its tributaries.

The form and distribution of remnants of the deeply weathered surface and the terraces are described in detail, and the relationships and regional extent of the land forms recognised in the field are further illustrated by cartographic analysis. This account of the land forms is followed by a discussion of their relationships to the soils of the area which have been previously described by Mulcahy (1959, 1960).

The relationships between soils and erosional and depositional surfaces are shown to be complex. The main conclusions are that most of the soils of the area are the result of geomorphologically relatively recent episodes; that youthful soils can occur on geomorphologically "old" sites; that sites inherited from the same stage of landscape evolution may have different soils; and that similar soils may occur on sites relating to different geomorphological stages.

A denudation chronology concludes the paper.

Introduction

This paper describes cyclic land forms in the Avon valley near York. Field work was confined to that part of the valley between Hamersley and Mount Hardey, however, detailed mapping of land forms was earried out during four weeks' field investigation of a small area shown in Figure 1. The land forms reeognised in the field are supplemented by eartographic analysis. Both field mapping and cartographie analysis were eoncerned only with land forms, however, Muleahy (1959, 1960) previously mapped in detail the soils of the area with particular reference to their development in relation to stages in the erosion of a lateritised land surfaee. Therefore, the aceount of the land forms in the present paper is followed by a discussion of their relationships to the soils as mapped and described by Mulcahy.

The upper Avon follows a north- to north-westerly course on the plateau surfaee of Western Australia. approximately parallel with the eoast and about 60 miles inland. At Toodyay it turns south-west through the escarpment and reaehes the eoast near Perth. The plateau surfaee in this area was named the Darling Plateau or Peneplain by Jutson (1912) and it is bounded on the west by the Darling Searp. It lies mainly between 800 and 1,000 feet above sea-level, rising very gradually eastwards.

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The Avon and its tributaries in the York area follow two main directions; north-north-west, eorresponding to the strike of the underlying rocks, and north-east or east-north-east, an important jointing and fracture trend (Fig. 2). The Avon valley here forms a trench between 500 and 600 feet above sea-level and a mile or so wide. Away from the river, the landseape is that of a sub-maturely disseeted plateau. To the west, dominantly on granite, the plateau is generally between 1,000 and 1,200 feet above sea-level. Where gneiss erops out it is interbedded with discontinuous quartzite bands and other meta-sedimentary lenses (Johnston 1952). These have been etched into bold steep-sided hills sueh as Mt. Mackie (900 ft.) and Mt. Bakewell (1,500 ft.). On the less resistant gneiss east of the river the plateau is between 750 and 850 feet above sea-level. Rising above, however, are the Needling Hills (1,200 ft.), formed on quartzite, and Mt. Brown (1,000 ft.) and Mt. Hardy (900 ft.) on granite. More resistant lenses in the gneiss show themselves as loeal slope breaks and minor valley-side benehes. Low narrow ridges are formed by granite and dolerite dykes, the most prominent of whieh have a north-north-west or north-east trend.

Field Methods

The benehed valley sides of the Avon are evidenee that ineision has taken place in stages, with gently inelined surfaces or "flats" corresponding to prolonged periods of base-levelling and steeper linking slopes representing the intervening periods of downcutting. A study of the valley was made to see if stages of downcutting and base-levelling could be reeognised.

Field work consisted of the reeognition of "flats" and breaks of slope, and mapping them using aerial photographs. In this eontext "flat" does not imply laek of slope. It is an aeeepted term as used by many geomorphologists (e.g., Linton 1948). The important eonsiderations in defining "flats" are the delimiting breaks of slope between the "flats" and the steeper linking slopes, and the break of slope at the lower margin of a "flat" is partieularly signifieant. This break is commonly relatively well-defined (see Figs. 3 and 4) and ean be measured to within a few yards and mapped with little difficulty. However, mapping is more difficult if this lower break of slope is a eonvex "eurved break of slope" (Savigear 1956). In this ease the lower margin of the "flat" is mapped at the measured upslope boundary of the convexity. Slope breaks determined by outcrops of more resistant rocks were distinguished from those

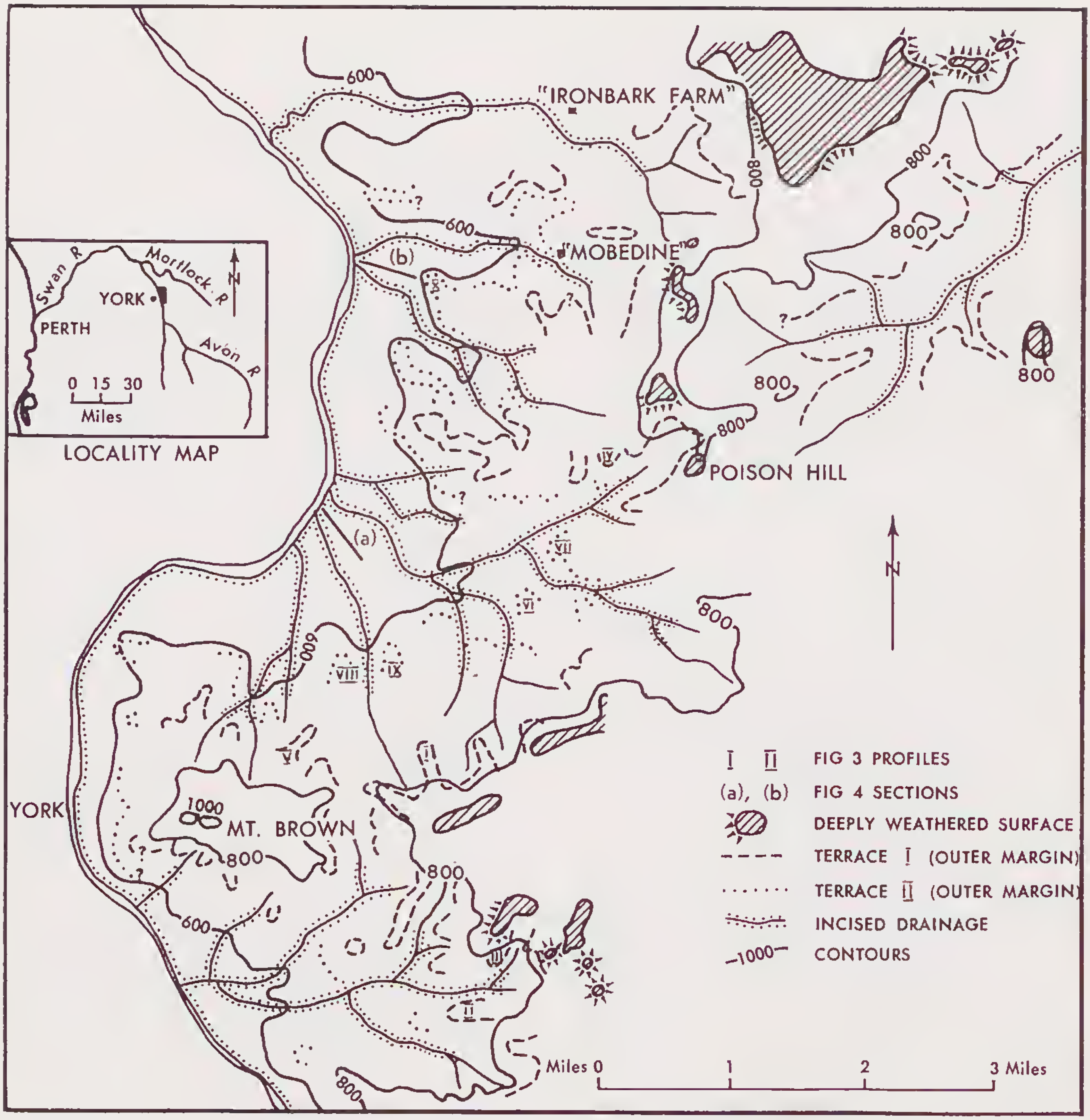


Fig. 1.—Distribution of cyclic elements in the landscape.

which transgressed structure and which were therefore interpreted as delimiting remnants of the sides and floors of former valleys.

Although field mapping was not extended to the Mortlock River, correlation of similarly staged terraces within the Avon and Mortlock catchments was established by their continuity across the watershed at higher levels.

A barometric altimeter was used to supplement map contour data (No. 400 York 1-mile series, Second Edition). Two sections were levelled and other slope angles were measured with an Abney level.

Cyclic Elements in the Landscape

Deeply Weathered Surface

Preserved on the higher parts of the crests of the main interfluves are the remains of what was formerly an extensive deeply weathered erosion surface, remnants of which are readily recognisable by their laterite cappings, delimiting breakaways, and general accordance of level. Although these remnants have been mapped by Mulcahy they are very restricted in area and, therefore, consideration of them is important if any attempt is to be made to reconstruct the nature of the original surface. Thus, a brief

description is given of the altitudes and forms of remnants in the area of detailed field work.

The largest remnant mapped (Fig. 1) is situated one mile east of Ironbark farm (862653)*, at an altitude of between 800 and 850 feet above sea-level, and forms part of the Avon-Mortlock watershed. The western and northern part of the residual consists of a broad rounded rise between 30 and 40 feet above the remainder, with a flat crest 60 yards wide. On the north and south flanks of the rise, slopes are relatively steep, attaining 4 per cent. Below the rise the surface slopes at 1 per cent. in the west, but elsewhere has no appreciable gradient. The remnant is delimited by breakaways between 10 and 30 feet high with slopes up to 40 per cent., except to the south, where the boundary is a long slope of between 3 and 4 per cent.

Immediately east of this residual, at slightly more than 800 feet above sea-level, is a smaller residual of the deeply weathered surface. Its crest slopes are up to 4 per cent., as on the Ironbark residual, and it is bounded by breakaways only slightly less pronounced than those of the larger residual.

* The figures in brackets are grid references on the York 1-inch map.

To the south of the Ironbark residual are four small remnants of the surface extending in a belt north to south. The northernmost one, east of Modedine (860632), is at a height of 800 feet. The second remnant is at 850 feet and is preserved on an outcrop of resistant rock which may account for it being somewhat higher than the other remnants. The third remnant is slightly less than one mile north-east of Red Knob (870611), and the fourth, worked for gravel, is crossed by the Goldfields Road at Poison Hill (880601).

Three miles east, at Collins Hill, (920623), is another small outlier of the surface at a little above 800 feet. This residual contrasts with other remnants of the old surface in that it has no delimiting breakaways. It is bounded by slopes less than 7 per cent.

East of Mt. Brown is another group of remnants of the old surface. These are generally at a height of 850 feet, but to the south an altitude of 900 feet is reached.

In this area, therefore, remnants of this erosion surface are found only on the watershed between the Avon and Mortlock Rivers and are, with one exception, very small.

These remnants east of the Avon are cut in gneiss and are between 800 and 900 feet

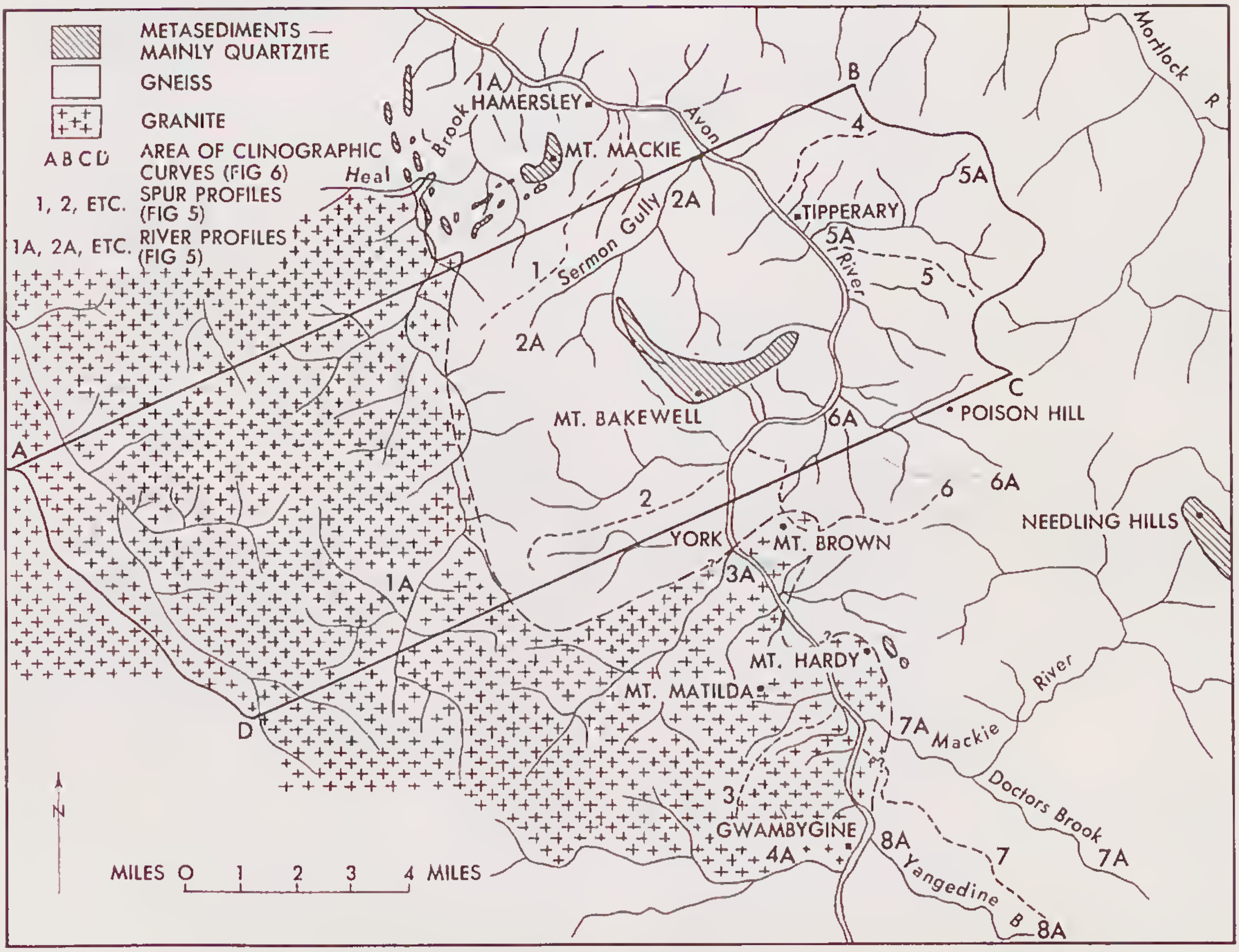


Fig. 2.—Geology and drainage.

above sea-level. West of the river, however, on the more resistant granite and meta-sedimentary rocks, remains of a laterite-capped surface which is correlated with that east of the Avon are 200 to 300 feet higher. Numerous dissected remnants, generally between 1,000 and 1,150 feet, extend from Mt. Ommanie (711657) in the north to the "Stockdale" (708472) area in the south.

Rising above the level of the deeply weathered surface are Mt. Bakewell (1,500 ft.) and the Needling Hills (1,200 + feet). Woolnough (1918) suggested that hills standing above the plateau level indicate an earlier surface which he named the "Mount Dale Level". Mt. Bakewell and the Needling Hills are satisfactorily explained as the topographic expression of resistant quartzites on the old erosion surface. There is no evidence of an earlier erosion surface in this area.

The Terraces

The deeply weathered surface has been strongly dissected by the Avon and its tributaries. Four stages are recognised between the old surface and the main channel. Corresponding to the first three stages are two rock-cut terraces and an alluvial terrace, each comprising backing "slopes" at its inner margin, furthest from the river, and lower, gently sloping "flats" as its outer margin, nearest the river. The fourth stage is represented by a later incision of the Avon and its tributaries. The break of slope between the "flat" of one terrace and the backing "slope" of the terrace below is shown on the map illustrating the distribution of remnants of the terraces (Fig. 1). The terraces can be traced almost continuously, rising upstream in the area mapped.

Terrace I.—The inner limit of the first stage of entrenchment is the breakaway which generally separates it from remnants of the deeply weathered surface. A long concave slope leads down to the terrace "flat" as much as 100 feet below. The terrace flat has been dissected into spurs with gently sloping crests, and the equivalent stage is continued into the adjacent tributary valleys by slope breaks and minor benches. The form of the Terrace I spurs is illustrated in Figure 3. Except for Spur IV, the crests are up to about 100 yards wide and 400 yards long with slopes of about 1 per cent. towards the river. Spur IV, at the head of a tributary valley, is gently rounded in cross-section with marginal slopes of 3 per cent. The margins of the crests generally slope at between 1 and 2 per cent. towards the steeper (up to 12 per cent.) flanks of the spurs. The backing slopes, leading up to and including the discontinuous breakaways of the deeply weathered surface, attain 7 per cent.

The terrace was mapped on the east side of the Avon valley, where it was seen to rise upstream and up both sides of tributary valleys. In the downstream part of the area it is generally at an altitude of 700 feet. However, below Mt. Brown it is at about 725 feet, and upstream it attains 800 feet near Quartz Hill (848518). The terrace rises away from the Avon to between 750 and 800 feet in the heads of tributary valleys, e.g., east of Ironbark farm and near Poison Hill.

Although the outer margin of the terrace occasionally coincides with outcrops of more resistant rocks it does not follow any one band for any distance and locally cuts across structure. Thus, in the tributary valleys west of Poison Hill, the terrace transgresses minor breaks of slope formed by thin bands of more resistant gneiss. Similarly, around Mt. Brown, the terrace leaves the gneiss and transgresses the granite.

The terrace was mapped in tributary valleys as well as in the main valley, as "paired" benches on both valley sides. What gradient there may be on these valley-side "flats" is towards the Avon and the remnants can be traced rising steadily up the main valley. In the tributary valley west of Poison Hill the longitudinal gradient of the old valley floor, measured from the surviving remnants of the terrace on the north side of the valley, is 2 per cent. towards the Avon.

These characteristics all point to this land form being the remains of a previous valley floor, a cyclic feature, and a distinct stage in the entrenchment of the Avon into the deeply weathered surface.

Terrace II.—This terrace occurs primarily as spur crests and also as restricted benches and slope breaks which occur on valley sides below the level of Terrace I. The spur crests are usually less than 100 yards wide and gently rounded in cross section (Fig. 3). They slope at between 1 and 3 per cent. towards the spur sides, which have gradients of up to 9 per cent. In longitudinal profile the crests slope at between 0.5 and 2 per cent. and are up to 300 yards long. The backing slopes are up to 7 per cent. but have local structural benches.

Terrace II is at an altitude of just above 600 feet in the downstream part of the area, rising to 650 feet at the head of the tributary valley in which Mobedine farm is situated. The terrace rises up the main valley and attains 700 feet south of Mt. Brown. It is also well-preserved near Hamersley (742699), extending from a mile or so east of Rivoli (736694), following the 600 feet contour westwards and rising up the valley of Heal Brook to an altitude of 650 feet west of Mt. Mackie.

Terrace II has been more closely dissected than Terrace I. Thus, it is preserved as rounded spur crests, with "flats" less typical than in Terrace I. It does, however, have the same fundamental characteristics as Terrace I. It cannot be explained by more resistant outcrops forming local base levels of denudation. Locally it cuts across them, as at Mt. Brown where it transgresses the granite boundary. In addition, the feature can be traced along both sides of tributary valleys, rising upstream. It is, therefore, interpreted as indicating a further stage of downcutting in the Avon valley.

Terrace III.—Unlike the older, rock-cut terraces, Terrace III is a depositional feature. It comprises the present valley floor of the Avon and the lower parts of tributary valley floors and represents a period of aggradation following the dissection of Terrace II. It is at an altitude of about 550 feet flanking the Avon River but rises to about 600 feet in the tributary

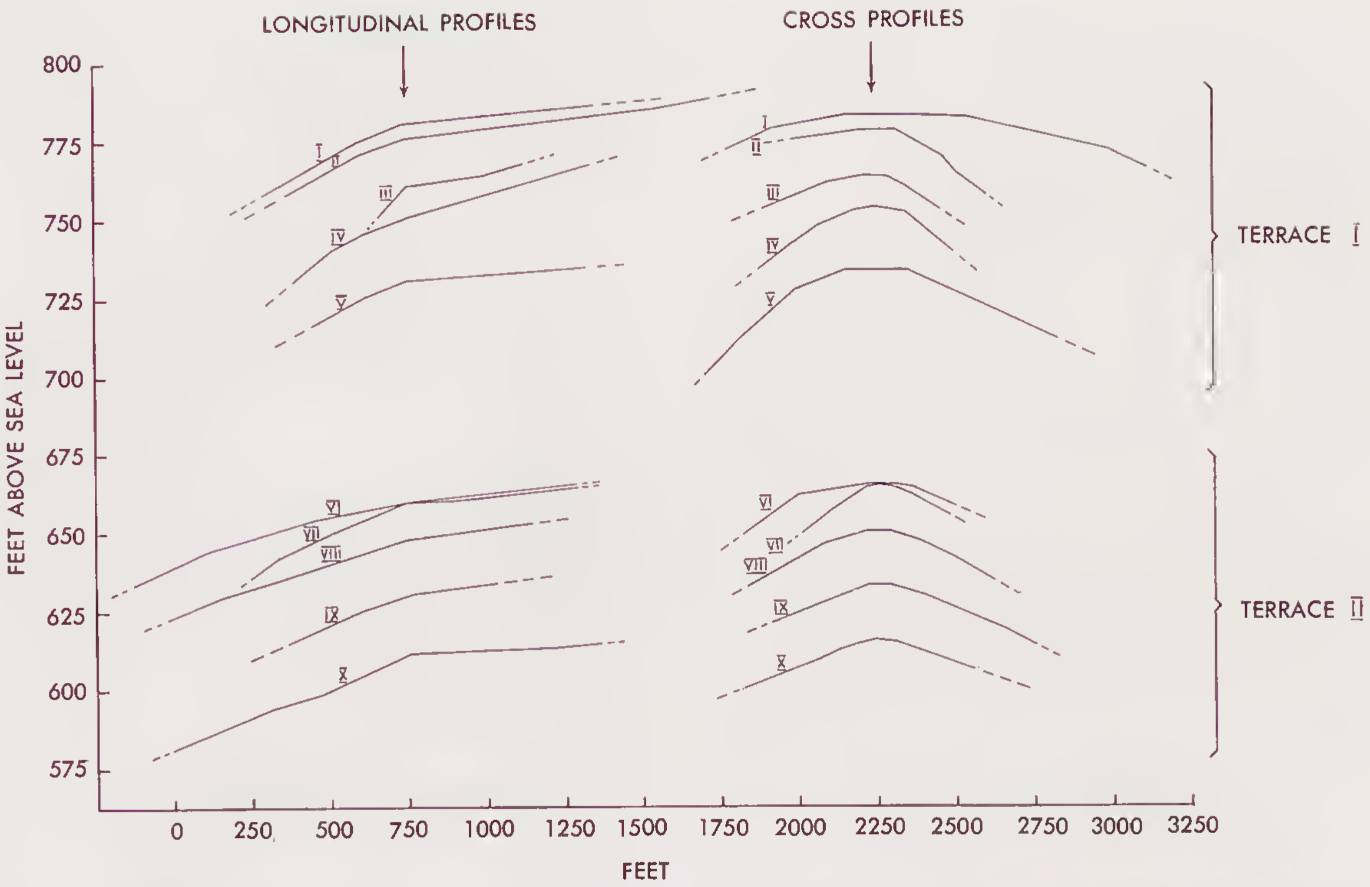


Fig. 3.—Profiles illustrating form and height range of Terrace I and Terrace II remnants (Vertical exaggeration x 10). Locations shown in Fig. 2.

valleys west of Poison Hill (880601). The range in form of the terrace is illustrated in Figure 4. It extends between ½ and 1 mile downslope and comprises outer "flats" between 100 yards and ½ mile long with gradients of about 0.6 per cent., and backing "slopes" up to about 3 per cent.

The deposits of the terrace embrace two sub-stages—an older deposit consisting of lateritised arkosic grits being overlain unconformably by younger fine-textured alluvium (Mulcahy 1959, 1960). The maximum exposed thickness of the grits is about 6 feet but the base was not seen. The younger alluvium is up to 15 feet thick in the area of detailed field work.

In the Avon valley numerous exposures of the grits in the floors of channels incised in Terrace III suggest that they are continuous beneath the alluvium of the terrace. These grits are correlated with similar deposits, called the Mortlock beds, which occur at a high level in the upper reaches of the Mortlock River and which occupy shallowly dissected valley floors cut in Terrace I—i.e., Terrace II stage sites. However, in contrast to the more or less complete lateritic profiles in the Mortlock valley, the deposits in the Avon valley have been truncated and then reburied by the younger alluvium (Mulcahy 1959, 1960).

Thus, Terrace III stage comprises two sub-stages—the first consisting of downcutting into Terrace II and the subsequent deposition of the Mortlock beds; the second consisting of erosion and truncation of the Mortlock beds followed by the deposition of fine-textured alluvium.

The Channel and Lower Flood-plains.—The youngest phase of downcutting has reached the stage where the Avon and its tributaries are incised up to 25 feet into Terrace III, and the channel floors are cut into the weathered grits (Fig. 4). Restricted lower flood-plains are forming locally. These occur marginal to the Avon and in the lower courses of tributary streams and are typically less than 100 yards wide.

Cartographic Analysis

Cartographic analysis of the York sheet (No. 400 1 mile-series, Second Edition) was applied after field work had been completed and after the cyclic features described above had been recognised. The aim of this analysis was to determine the regional significance of these features and to illustrate their forms and their relationships to each other.

Projected Profiles

Projected profiles (Barrell 1920) were constructed for that part of the Avon valley between Gwambygine (825453) and Hamersley (742699), with parallel lines of section drawn normal to the general trend of the valley (Fig. 5a). This technique projects surface levels over a wide area into one view to attempt to illustrate the original forms of surfaces since dissected. Similarly, by projecting features related to stages of downcutting and base levelling—valley side benches and "graded" valley floors—it could

also be expected to show the relationships and distribution of such intact forms in different parts of the catchment.

The profiles were simplified and the various levels emphasised by showing only interfluve crests, valley side benches and valley bottoms, and omitting connecting slopes.

The most striking feature on the profiles is that the "reconstructed" deeply weathered surface is shown to be considerably lower east of the river that to the west. East of the Avon it is generally 800-850 feet above sea-level, rising away from the river to 900-950 feet. However, west of the Avon this old surface is usually at 1,100-1,150 feet attaining 1,200 feet or so away from the river and sloping gently to 950 feet close to the Avon. Mt. Bakewell and the Needling Hills rise well above the general level of the surface.

The profiles illustrate Terrace I and Terrace II stages of downcutting, shown as the valley bottoms of entrenched tributary streams and the valley side benches of the Avon.

West of the Avon, Terrace I stage is indicated at about 700 feet close to the river, and by broad valley bottoms rising away from the river to 850-900 feet and more in the extreme west. East of the river this stage is reflected in benches at 700-750 feet and in the level extending eastwards at 750 feet.

Terrace II stage is seen in benches at 600-650 feet near the Avon and in broad valley bottoms at this level east of the river, rising to 700 feet in the extreme east. West of the Avon, Terrace II stage valley bottoms rise from 650 feet near the main river, reaching 800 feet in the west.

Terrace III is illustrated by the broad "flat" at 550 feet west of the river.

River and Spur Profiles

River profiles were drawn because it might be expected that, after rejuvenation, the surviving portion of an earlier profile would meet the developing new profile in a nickpoint of characteristic form. If such convexities or breaks in the profile had cyclic significance they would be expected to relate to remnants of the earlier valley floors now preserved at terraces downstream from the nickpoints. Therefore, spur profiles were drawn in conjunction with the river profiles to verify whether these cyclic relations occurred. Figure 5 (b and c) shows the profiles, and their location is shown on Figure 2.

Structural differences may explain breaks in river profiles. However, in view of the highly foliated nature of the underlying rocks, it is unlikely that structural differences could cause corresponding breaks in the river profiles and levels on the spur profiles. Neither could underlying structure result in the formation of the distinct levels that characterise all the spurs.

In the western tributaries of the Avon, Terrace I stage nickpoints range in height from 750 to 950 feet, depending on how much the lower profiles of this stage have been destroyed by Terrace II rejuvenation. Nickpoints occur at 650-800 feet where Terrace III stage rejuvenation meets the Terrace II stage valley floors.

Only two nickpoints are revealed in the river profiles east of the Avon. These are at 750 feet and may represent the junctions of Terrace II stage and Terrace III stage profiles. The absence of other breaks in the streams east of the Avon may be due to more rapid regrading on the less resistant rocks of that part of the area.

The spur profiles illustrate the associated valley-side features. West of the Avon Terrace I remnants are preserved at 750-800 feet and Terrace II remnants at 650 feet on all the spurs. East of the river these stages are indicated at 700-750 feet and at 600-650 feet on the spur profiles.

Clinographic Curves (Fig. 6)

Areas between successive contours were measured and clinographic curves (Hanson-Lowe 1935) were drawn for part of the valley

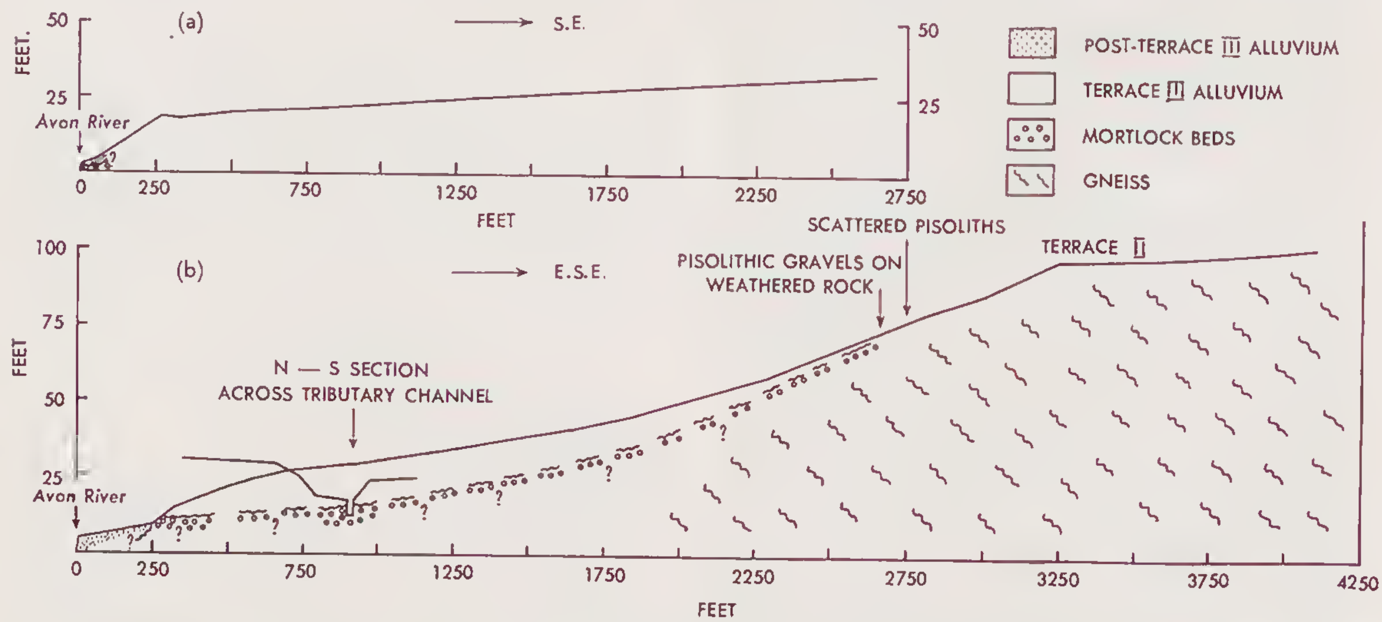


Fig. 4.—Terrace III sections showing (a) the "flat" where terrace is broad, and (b) the whole feature where terrace is narrow. (Vertical exaggeration x 10). Locations shown in Fig. 2.

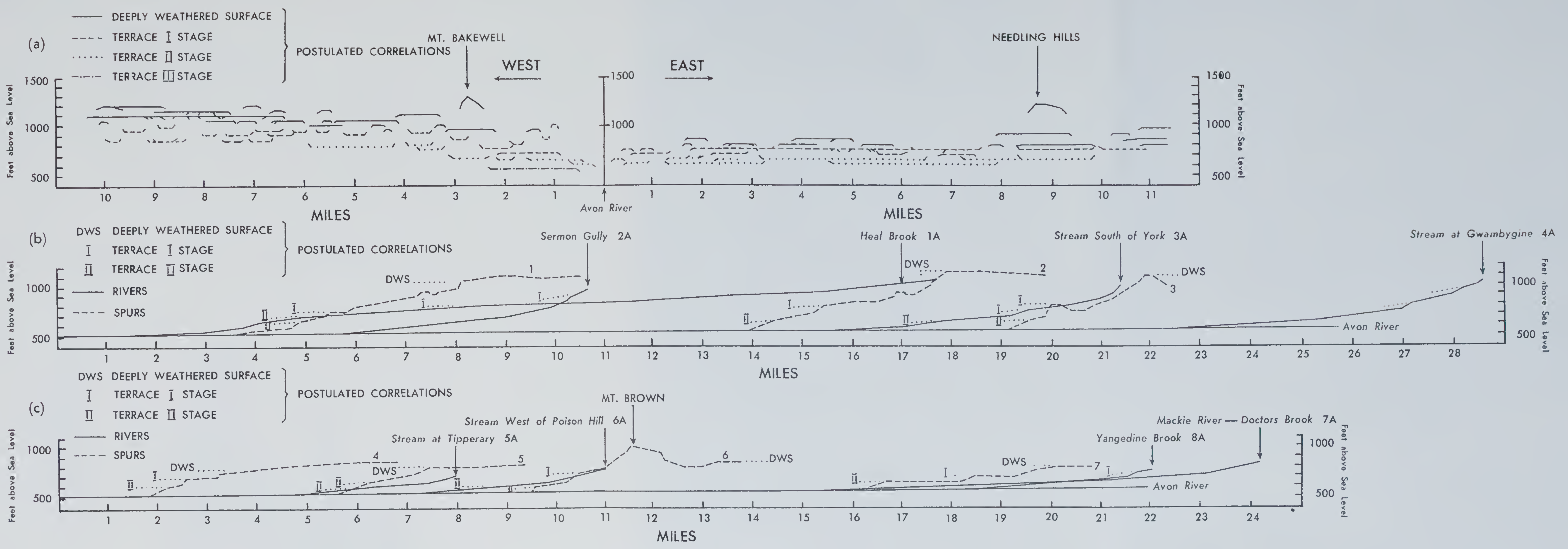
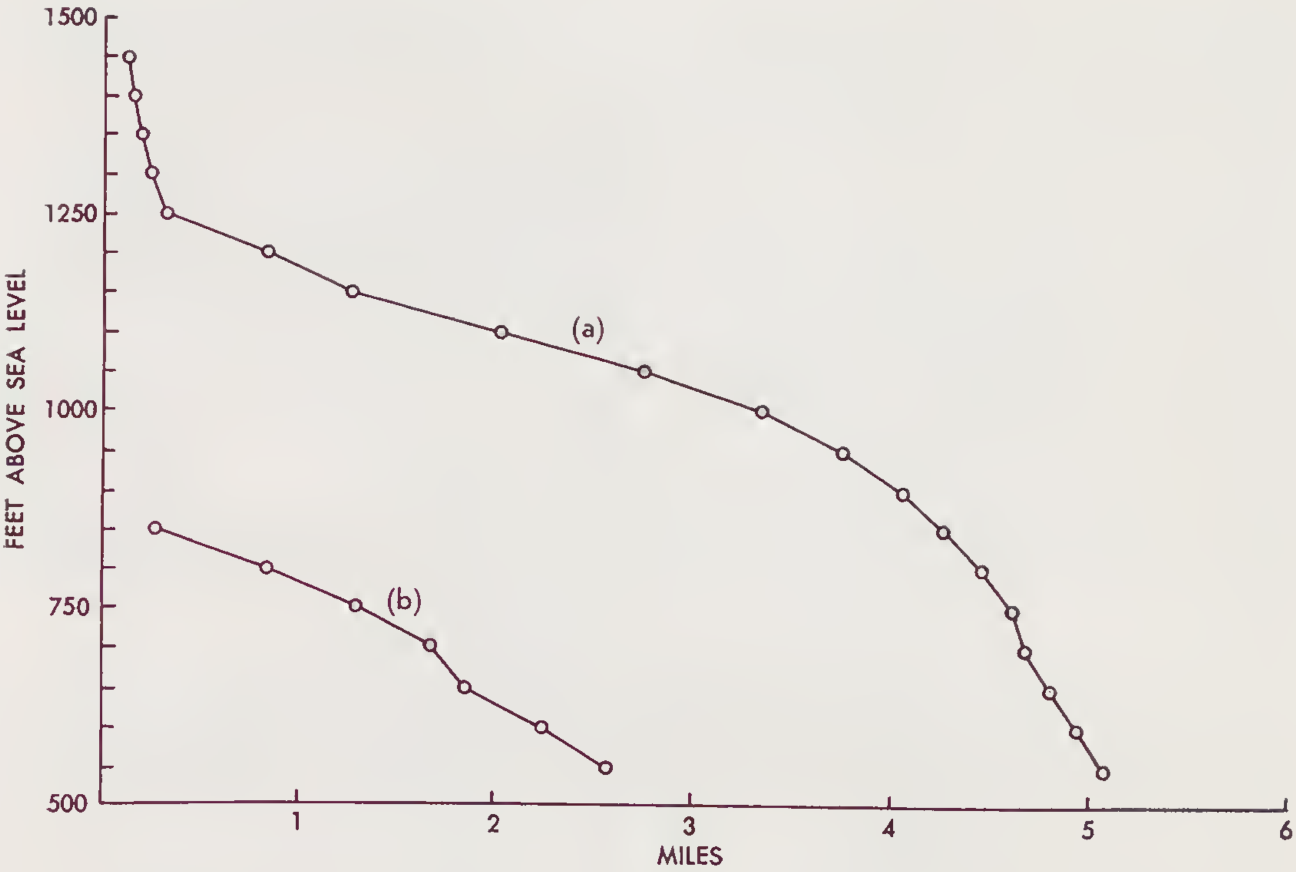


FIGURE 5. Profiles in the York area showing (a) projected profiles looking downvalley, (b) river and spur profiles west of the Avon, and (c) river and spur profiles east of the Avon. (Vertical exaggeration x 10). Locations shown in Fig. 2.



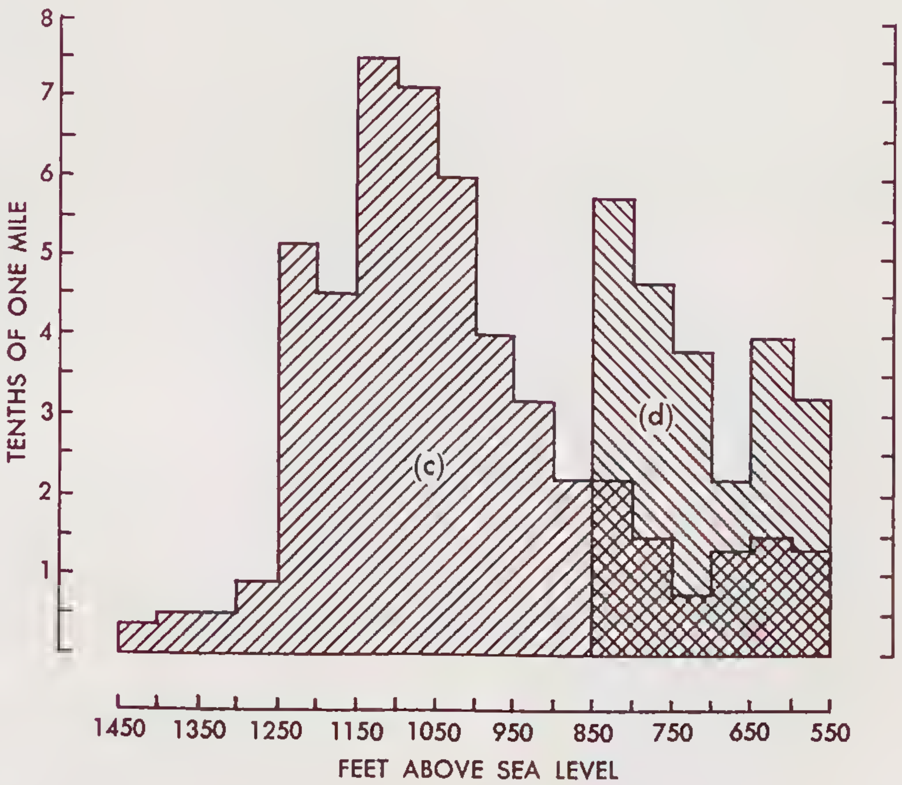


Fig. 6.—Clinographic curves (a) west of the Avon, and (b) east of the Avon. Histograms showing differences in successive radii, (c) west of the Avon, and (d) east of the Avon.

west of the Avon and part to the east (area ABCD on Fig. 2).* Histograms were drawn showing the differences between successive radii used in constructing the clinographic curve.† These have considerable usefulness in emphasising slope changes; the convex lower margins of relatively gently sloping sectors of the curve appear as maxima, whilst the backing concavities appear as minima.

West of the Avon.—The level of the deeply weathered surface here is reflected by a gently sloping section in the clinographic curve (Fig. 6a) at 1,000-1,150 feet and by a broad maximum between these levels on the histogram (Fig. 6c). Hills above are indicated at 1,150-1,250 feet in the curve and by a slight maximum on the histogram. The top of the curve rises sharply to Mt. Bakewell, above 1,450 feet.

Terrace I stage incision into the upland surface is represented by the steepening of the curve at 1,000 feet and by decreasing column heights on the histogram. The gentler lower slopes of this stage cause a break in the continuity of decreasing column height at 800-850 feet.

The further steepening of the curve below 750 feet, and the histogram minimum at 700-750 feet mark the upper limit of Terrace II stage incision. The convexities bounding the lower slopes of this stage are indicated by a slight maximum at 600-650 feet on the histogram.

Terrace III stage downcutting is not shown by the curve or by the histogram.

East of the Avon.—The clinographic curve (Fig. 6b) indicates that there is a greater area of country at 800-850 feet than between successive contours at lower levels. The flattening of the curve at 800-850 feet probably records the existence of both deeply weathered surface remnants and Terrace I "flats". This may be due to the fact that remnants of the deeply weathered surface are small, or that the vertical interval between them and Terrace I is less than 100 feet, or that the connecting slopes between the deeply weathered remnants and Terrace I are gentle.

The steepening of the curve at 650-700 feet and the histogram minimum between these levels indicate the striking slope change associated with vigorous Terrace II stage incision. The flattening of the curve at 600-650 feet and the corresponding histogram maximum illustrate the change to the graded lower slopes of Terrace II.

A very slight steepening below 600 feet in the curve indicates Terrace III stage incision.

Land Forms and Soils

Mulcahy (1959, 1960) has correlated the soils of the area with a number of "erosional and depositional surfaces". His Quailing surface consists of a laterite which occupies the highest parts of the landscape. The Kauring surface is a younger laterite which occurs at a slightly lower level. The Quailing and Kauring surfaces are regarded by Mulcahy as part of the "Old Plateau" (Jutson 1934) and thus he deduces that the laterite has formed in at least two stages.

Sandy deposits derived from the Quailing and Kauring surfaces and named the Quailing depositional and Monkopen surfaces form features termed "spillways".

Mulcahy believes that rejuvenation of drainage in this area took place in response to post-Tertiary uplift and that this resulted in a number of "erosion cycles". The oldest of these is represented by the Belmunging and Mortlock surfaces, "the remnants of the sides and floors respectively, of valleys cut in the old plateau" (Mulcahy 1960, p. 211).

His second cycle is represented by the Balkuling surface which is a pediment cut in the transitional and pallid zones. It is extending by the retreat of "breakaways which bound the old plateau and the Belmunging surface and hence it must be younger than both of them" (Mulcahy 1960, p. 213).

Mulcahy's youngest "cycle of erosion" is represented by the York and Avon surfaces, the upper limit of which is marked by "a slight increase of slope" (Mulcahy 1960, p. 214) below the Balkuling surface. Mulcahy and Hingston (1961) mapped three soil types on the York surface—shallow stony soils (Y1 in Fig. 7), red-brown earths (Y2 and Y3 in Fig. 7), and poorly drained soils (Y4 in Fig. 7).

The Mobedine surface of Mulcahy occurs as a scree forming the noses of ridges at about the 600 feet contour in the Avon valley.

Summarising, therefore, Mulcahy recognises three cycles of erosion resulting from the rejuvenation of drainage whereas four stages in the downcutting of the Avon into the deeply weathered surface have been recognised in the field by the author and described above. Because of this, and in view of Mulcahy's assertion that "the field evidence, then, shows that a good correlation exists between the distribution of the soils and that of the major geomorphic surfaces, for which a relative age sequence can be established" (Mulcahy 1960, p. 215), the distribution of soils is reviewed in the light of the four stages recognised geomorphologically.

The soils as mapped by Mulcahy and Hingston (1961) and the cyclic elements recognised here in an area exetending north-east from Mackies Crossing are shown in Fig. 7. Because of the complexity of this map, Fig. 8 shows typical relationships between the cyclic land forms, weathering zones, superficial deposits and soils, generalised in three dimensions for most of the area shown in Fig. 7.

The Soils of the Deeply Weathered Surface

The Quailing laterite is found on the higher and lower parts of the largest remnant of the deeply weathered surface east of Ironbark farm, with the Quailing and Monkopen depositional materials essentially on the slopes fringing the higher part and extending down into the heads of dissecting streams. The sites of the Kauring

* In the clinographic curve the radii of circles equal in area to that within each contour (x axis) are plotted against height above sea-level (y axis) to give mean gradients.

† The author is grateful to J. A. Mabbutt of the Division of Land Research and Regional Survey for suggesting the construction of these histograms.

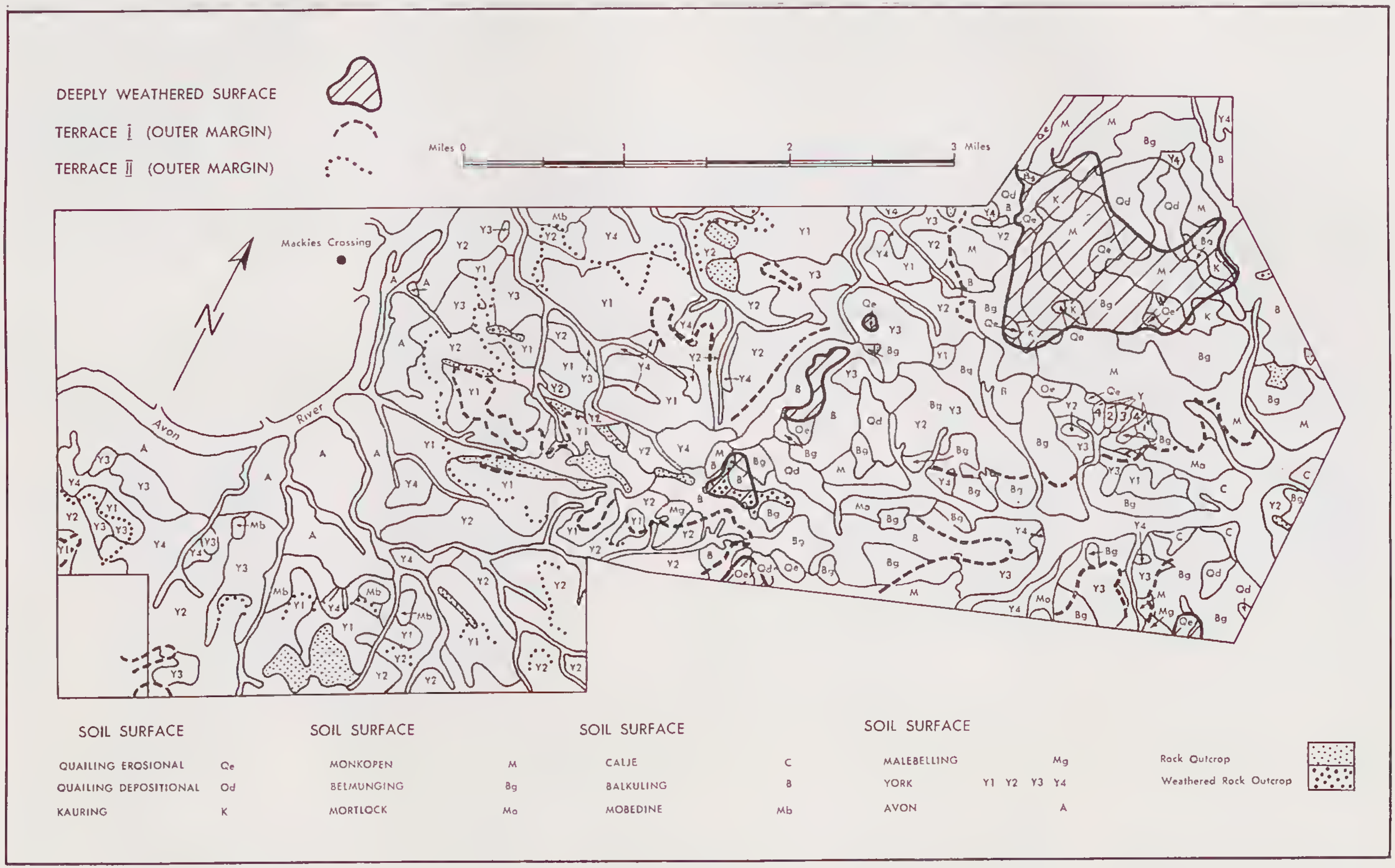


Fig. 7.—Distribution of soils as mapped by Mulcahy and Hingston (1961) and of cyclic elements as in Fig. 1, in an area extending north-east from Mackies Crossing.

laterite are at the margins of the Ironbark residual, in areas of waxing slope development. On the north and east they occur immediately above the dissection heads of tributaries of the Mortlock River. The Belmunging soil surface also occurs on the lower parts of the Ironbark residual but extends downslope transgressing the boundary of the remnant. The other remnants of the deeply weathered surface typically carry only the Quailing laterite with some Quailing depositional sands but the Balkuling and Belmunging soil surfaces, with exposures of weathered rock, are found on the remnant immediately north-west of Poison Hill.

Terrace I Soils

Terrace I stage sites carry a variety of soils. In that part of the area drained by the Mortlock headwaters, the Belmunging soil surface occurs extensively on the inner slopes below remnants of the deeply weathered surface, generally where these are not bounded by breakaways. Good examples are found immediately north and south of the Ironbark residual and on slopes marginal to the Collins Hill residual.

Immediately south of the Ironbark residual of the deeply weathered surface there is a small outlying remnant of the Quailing laterite which forms a bench on Terrace I. Here, therefore, the terrace must be cut in the uppermost parts of the old deep weathering profile.

The Balkuling soil surface is found downslope from remnants of the deeply weathered surface but is usually separated from these by breakaways. The soils have as their parent material the pallid zone of the Quailing and Kauring laterites or weathered rock. They occur on pediments below the breakaways occasionally extending downslope on to spur crests formed by the remains of Terrace I "flats", particularly east and south-east of Mt. Brown. Here, at the heads of tributary valleys, the base level for Terrace I downcutting was within the pallid and transitional zones of the weathering profile. Elsewhere, however, Terrace I downcutting proceeded below the depth of weathering and in these situations the York red-brown earths generally occur on the lower parts of the terrace, where it is cut on unweathered rock. In addition, Terrace I has locally been closely dissected into rounded spurs at the heads of tributary valleys, and these remnants carry the shallow stony variety of the York soils (e.g., profile IV, Fig. 3).

Terrace II Soils

Terrace II sites in the Avon valley are mainly characterised by the shallow stony soils which form part of the York soil surface, and these occasionally extend up to the inner slopes. However, York red-brown earths also occur on the terrace. Certain tributary valley heads of this stage of downcutting are the principal sites of the poorly drained variety of the soil comprising the York soil surface. York red-brown earths also locally occur in the floors of these tributary valleys.

In addition, the Belmunging soil surface occurs on certain Terrace II sites in the headwaters of the Mortlock, mainly the inner slopes of the terrace. This is well illustrated one and a half miles north-east of Poison Hill on the slopes below a large remnant of Terrace I (903620). These sites are often less than 50 feet above the main tributary channel and locally the Belmunging soil surface extends down on to gentle slopes only a few feet above, and 100 yards or less from the channel. In the more dissected valley of the Avon, where post-Terrace II stage downcutting and base levelling is much further advanced, similar Terrace II sites (without Belmunging soils) are about 100 feet above the main channel.

The Mortlock surface occurs downslope from the Belmunging surface in the floors of the Mortlock and its tributaries, which have been interpreted as shallowly dissected Terrace II stage "flats".

In this area, the deposits of the Monkopen soil surface are associated with the Ironbark residual of the deeply weathered surface. They originate on the residual and "spill" out through the breakaways to occupy pre-existing valleys cut through Terrace I. To the south-east of this residual, however, the deposits spread out on to the low interfluves between the valleys and extend down on to the gentle lower slopes, cut during Terrace II stage. They also locally overlie the restricted slopes cut during Terrace III stage incision.

All the spillways in the present area, with one exception, are confined to the Mortlock headwaters. The exception is a small spillway at the head of the Avon tributary which flows past Ironbark farm (862653).

Terrace III Soils

The most extensive soil type associated with Terrace III is the alluvium of the terrace itself—the solonized grey or brown soils of the Avon surface. Exposures of underlying grits in tributary channels incised in to the terrace form part of the Mortlock surface.

The Mobedine surface occurs at the inner margin of Terrace III in the Avon valley. It is found on the slopes below the noses of spurs, the crests of which are Terrace II remnants.

Lastly, areas of the York soil surface, mainly the shallow stony soils but locally also the red-brown earths and poorly drained soils, occur in tributary valleys on the floors and adjacent slopes cut during Terrace III stage downcutting.

Discussion

The limited distribution of the Quailing and Kauring laterite residuals in this area makes any ambitious interpretations impossible. From the geomorphological evidence they could satisfactorily be regarded as the remains of an undulating surface on which the Quailing laterite developed and subsequently underwent varying degrees of stripping. In the area of detailed field work, the Kauring laterite is found above Terrace I stage dissection heads or in other areas of waxing slope development, that is, on sites where the Quailing laterite has been truncated. These sites would appear, therefore, to be related to the advance of Terrace I stage downcutting into the surviving remnants of the deeply weathered surface. Alternatively,

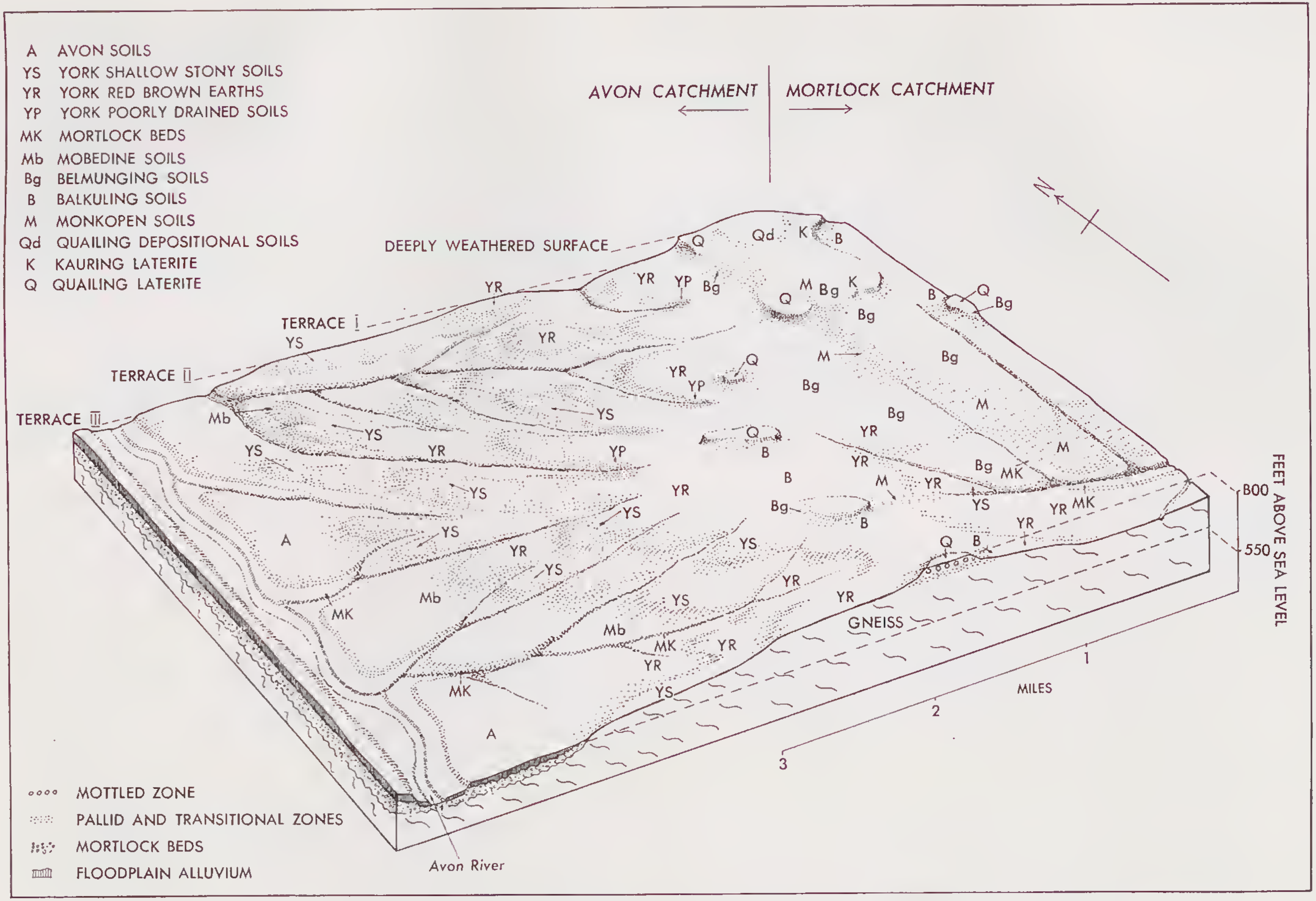


Fig. 8.—Relations between cyclic land forms, weathering zones, superficial deposits and soils as mapped by Mulcahy, generalized for the area shown in Fig. 7.

a pre-Terrace I stage of downcutting could be invoked to explain the truncation of the older laterite. However, there is no geomorphological evidence to suggest this and the first hypothesis is favoured.

Remnants of the Quailing and Kauring laterites show distinct and restricted occurrences on the watershed between the Avon and Mortlock Rivers. The geomorphic relationships of the younger soil surfaces are more complex and they are not necessarily restricted to any of the cyclic surfaces recognised here. This is illustrated by the extension of the Belmunging and Monkopen soil surfaces from the deeply weathered surface across Terrace I and Terrace II and on to younger sites.

The degree of truncation of the weathering profile has influenced subsequent soil development on Terrace I sites. Balkuling soils occur where the terrace is cut in weathered rock; downslope, where it is cut on unweathered rock, York red-brown earths are found.

The formation of the spillways probably indicates conditions of surface instability such as would be induced by a change to drier conditions resulting in a reduced vegetation cover. This would lead to the movement of sandy material from remnants of the deeply weathered surface into the upper parts of tributary valleys and to a reduction in the competence of streams to carry away the derived material.

The occurrence of more than one band of ferruginous concretions within the deposits possibly indicates a number of depositional "periods" separated by soil forming "periods" (Mulcahy 1959, p. 46).

The only geomorphological evidence for the age of the spillways is that the bulk of the deposits occur in valleys cut through Terrace I but that the youngest sites on which they occur are the slopes cut below Terrace II. Therefore, they are mainly post-Terrace I in age, whilst the youngest deposits at least formed during Terrace III stage. On geomorphological grounds, therefore, it is possible that the spillway deposits are, in part at least, linked with the Mortlock deposits. Some support is given to this by the contiguity of the spillway and Mortlock deposits in many parts of the Mortlock valley as mapped by Mulcahy. The coarse arkosic sediments of the Mortlock surface also indicate an extensive aggradational phase and may be due to the same change to increased aridity postulated to have resulted in the deposition of the spillways. In the Avon valley this aggradational phase is dated as part of Terrace III stage, although equivalent deposits and the tributary spillways occur on Terrace II stage sites in the upper reaches of the Mortlock. However, Mulcahy has emphasised the multiple nature of the spillway deposits and it is entirely feasible that the spillways may have operated at all stages in the destruction of the deeply weathered surface, from Terrace I stage onwards. Therefore, the formation of the spillways is not restricted to any geomorphological stage in the concluding denudation chronology.

The Mortlock deposits have been subsequently lateritised. The greater degree eof weathering of these deposits compared with those of the spillways could partly reflect site differences—the Mortlock deposits occur on relatively poorly drained valley floors whereas the spillways occupy more freely drained tributary valleys. In addition, the spillway sands being derived from the old laterites might not be capable of further weathering, whereas much of the Mortlock deposits were no doubt derived from valley sides downslope from the old laterites and would, therefore, contain material which would weather readily.

The Belmunging surface could have developed on the valley sides during this second period of lateritisation. It is noteworthy that the Belmunging surface is absent from the Avon valley. Firstly, this may be because it was never well developed on the steeper slopes of the more dissected Avon valley, although in fact there are numerous "flats" and gentle slopes where it could have done so.

Secondly, subsequent rejuvenation and dissection, which have been very active in the Avon valley, could have removed all trace of the Belmunging surface. This same rejuvenation has not yet attacked the headwater areas of the Mortlock to the same extent and Belmunging remains are preserved there. The truncation of the Mortlock layer beneath the alluvium in the Avon valley testifies that such erosion has in fact occurred. The pisolithic gravels of the Mobedine surface and the scattered pisoliths which occur upslope from it (Fig. 4b) may have been derived from a soil which was related to the Belmunging surface and which has been removed from the Terrace II "flats" above. However, the Mobedine gravel is different from that of the Belmunging surface (Mulcahy, personal communication).

Lastly, the Belmunging surface in the Mortlock catchment may be associated with part of the truncated deeply weathered profile—and the greater part of the Avon valley is cut below the level of that zone of weathering.

Thus, the pattern of soils in the York area indicates that a phase of surface instability, probably due to the change to more arid conditions, occurred during a first Terrace III substage. This could have resulted in the accumulation of the Mortlock materials and of much of the spillway deposits. The Belmunging, Mobedine and Mortlock surfaces, and possibly the Kauring laterite, could indicate a younger weathering phase. The erosion which truncated the Mortlock profile in the Avon valley during the second Terrace III sub-stage may have removed the Belmunging surface and the spillways from the valley. As a result the York surface and the related Avon deposits formed extensively in the Avon valley and locally in the Mortlock valley.

Conclusions

In contrast to the three "cycles" of erosion described by Mulcahy (1960, p. 211) and the two "cycles" he writes of most recently (Mulcahy and Hingston 1961, p. 32), here, four stages are recognised in the downcutting of the Avon into the deeply weathered surface. Obviously, therefore, soil surfaces cannot be identified with cycles of erosion as implied

by Mulcahy. Thus, in this section of the Avon valley there is a very complex relationship between the soils as mapped by Mulcahy and erosional and depositional surfaces recognised by detailed geomorphological analysis. This complexity is to some extent resolved by the following conclusions:—

(1) In the York area all the soil surfaces other than the Quailing and Kauring laterites are seen to extend on to Terrace II and even younger sites and are, therefore, the result of relatively recent episodes in the evolution of the physical landscape. The Balkuling soil surface, which alone is restricted to higher levels, is associated with active pediments and, therefore, in part at least, must be very "young" geomorphologically.

(2) Youthful soils can occur on geomorphologically "old" sites where these have been stripped of an earlier soil. This is expressive of the fact that land forms survive when their soil cover has been removed. Thus the York shallow stony soils are particularly associated with Terrace II sites and are occasionally developed on Terrace I sites.

(3) Sites inherited from the same stage of landscape history may have different soils. For example, Terrace I has been shown to truncate the deeply weathered profile and, therefore, it offers different sites for soil development based on differences of parent material.

(4) Since the inception of geomorphological stages occurs at different times in different parts of an area and since one stage continues its development after the inception of later stages, stage in the geomorphological sense does not have a strict time connotation and need not correspond with one period of soil formation. Thus, similar soils may occur on sites relating to different geomorphological stages. For example, the deposition of the Mortlock layer occurred on the Terrace II stage valley floor of the Mortlock and the Terrace III stage floor of the Avon. Similarly, one of the youngest of Mulcahy's surfaces, the York surface, occurs on sites with similar physical characteristics but which relate to different geomorphological stages.

These conclusions illustrate the complexity of correlating soils and stages of geomorphological evolution. Nevertheless, one example of the value of analysing the relief of an area to see how far stages of downcutting and base-levelling could be recognised, could be in relating laterites occurring at different levels in the landscape. For instance Playford (1954) has suggested that laterites occurring at differing levels in Western Australia formed during one period of deep weathering. If these laterites transgress land forms relating to different geomorphological stages, they could have been formed during one period of deep weathering. If, on the other hand, laterites at different levels are separated by one or more stages of downcutting which truncate higher laterites then the lower laterites would obviously be younger.

Denudation Chronology

The main stages of landscape development in the York area may be summarised as follows:—

(1) The formation of the deeply weathered surface.—This is the earliest recognisable stage in the history of the present landscape and indicates a prolonged period of base-levelling and the production of a laterite profile.

(2) The Terrace I stage.—Consisting of rejuvenation, downcutting and base-levelling into and below the deeply weathered surface, with the possible initiation of spillways.

(3) The Terrace II stage.—Consisting of rejuvenation, downcutting and base-levelling into the Terrace I stage valley floors, possibly with continuing spillway activity.

(4) The Terrace III stage.—

(i) Sub-stage 1.—This sub-stage was initiated by rejuvenation of the rivers and downcutting into the Terrace II stage valley floors. Broad valley bottoms were eventually produced below Terrace II.

A change to drier conditions caused the deposition of the Mortlock beds in valley bottoms and the filling in of tributary valleys by "spillways".

A subsequent weathering phase resulted in lateritisation of the Mortlock beds, the formation of the Belmunging soil on valley sides, and possibly the development of the Kauring laterite on sites where the Quailing laterite had been truncated.

(ii) Sub-stage 2.—The rivers were then rejuvenated and, in the Avon valley, the Mortlock layer was truncated, the "spillways" were removed from tributary valleys, and the Belmunging surface was stripped from the adjacent interfluves. The Mobedine surface may have developed where lateritic gravel, derived from the Belmunging or a related profile, accumulated on slopes cut in weathered or relatively fresh rock marginal to the Avon valley bottom.

This rejuvenation did not invade the headwaters of the Mortlock to the same extent, and the spillways and the Mortlock and Belmunging soils are preserved there as a result.

The latter part of this stage was marked by the deposition of the Avon alluvium and the

formation of York soils where older soils had been stripped from the sides of the main valley.

(5) The post-Terrace III stage.—A further stage of downcutting has resulted in the incision of the rivers into the Terrace III stage valley floor, and small flood-plains are developing locally below Terrace III.

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